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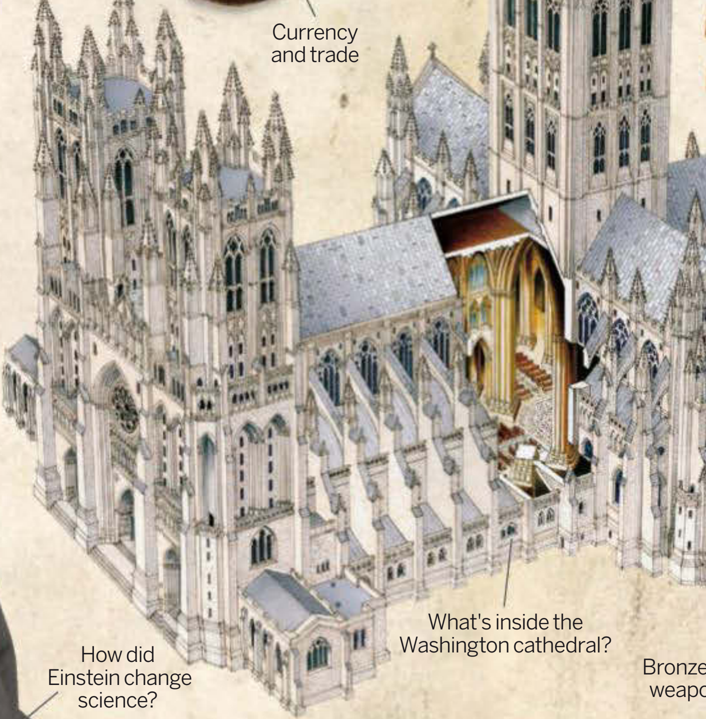
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What were the first cities of the ancient world like? How big *were* dinosaur teeth? How did pirates battle their way up to become the terror of the seven seas? Why was the Terracotta Army found buried beside the tomb of a Chinese Emperor? The How It Works Book of Incredible History is dedicated to answering all these questions and many more. In this new edition we journey through the ages and celebrate history's most intriguing customs, traditions and inventions – ones which changed the world forever. Not only will you traverse time periods, you will tour time zones via our eclectic range of subjects: the ancient world, iconic buildings and landmarks, weapons and warfare, masterful inventions, influential visionaries and prehistoric predators. Packed with fascinating facts and figures accompanied by gorgeous photographs, diagrams and illustrations, turn the page and be inspired as history is brought to life before your eyes!

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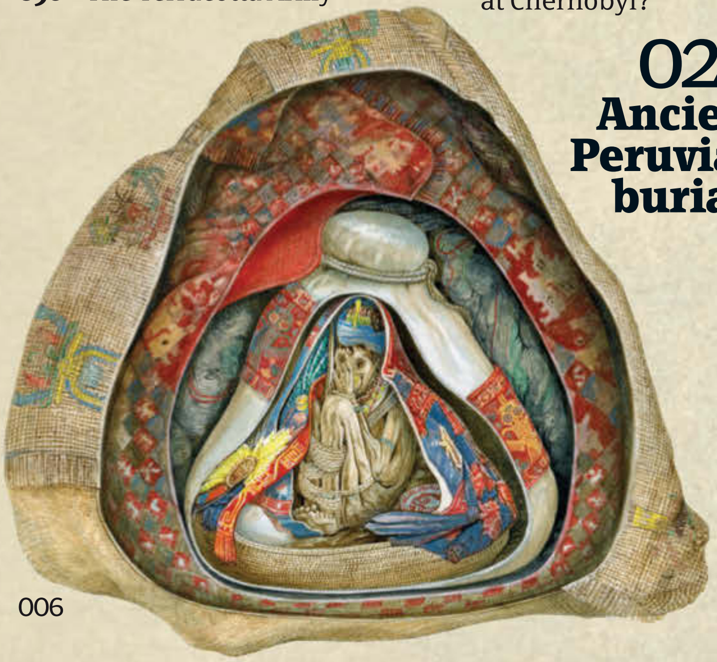

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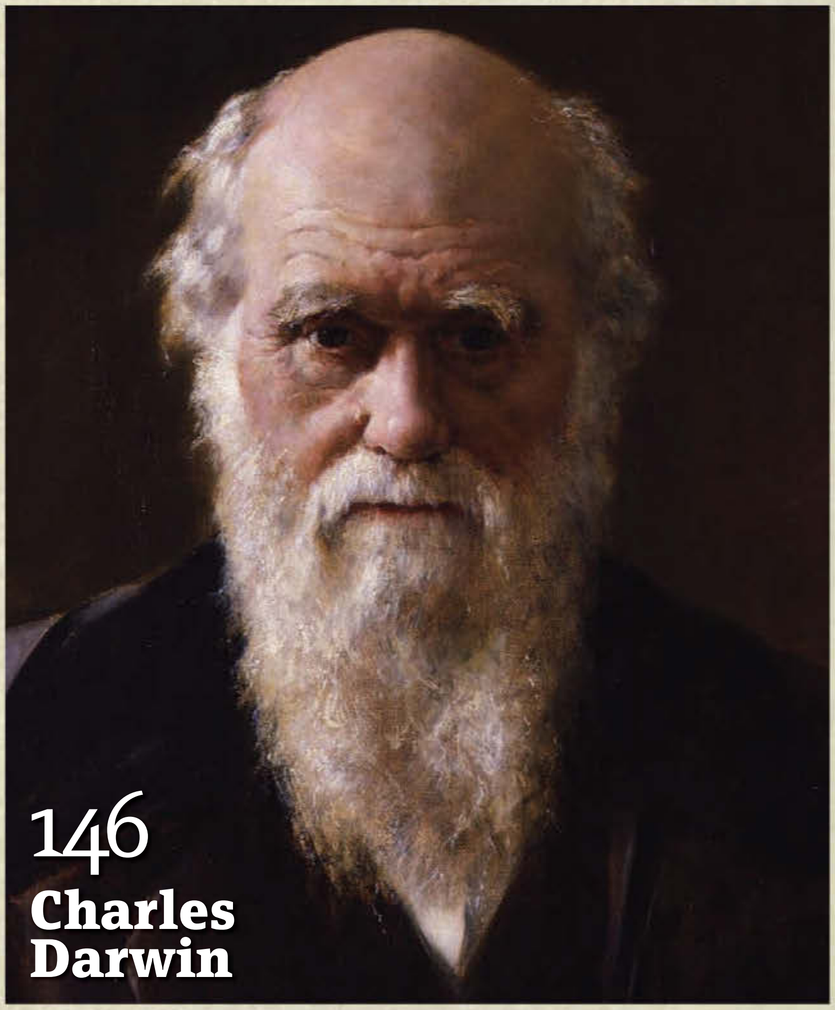

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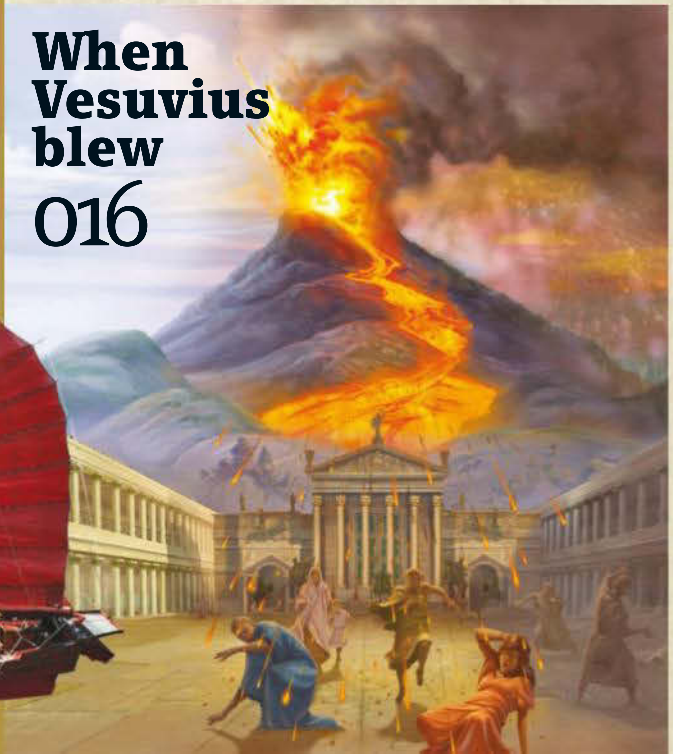

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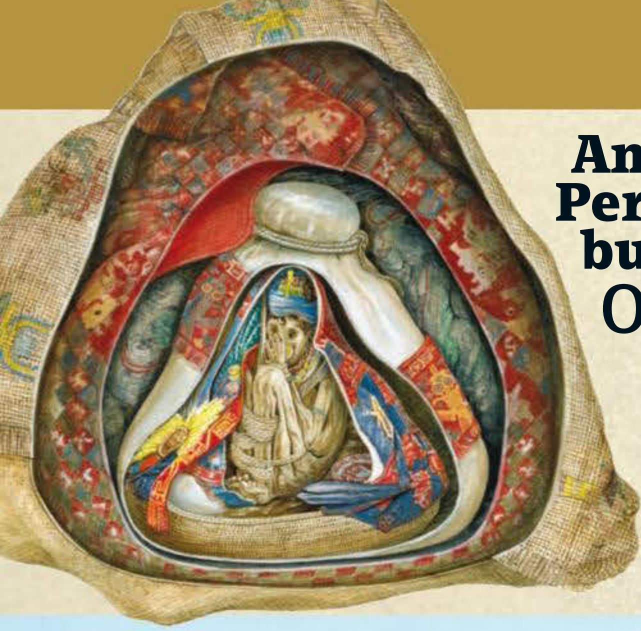

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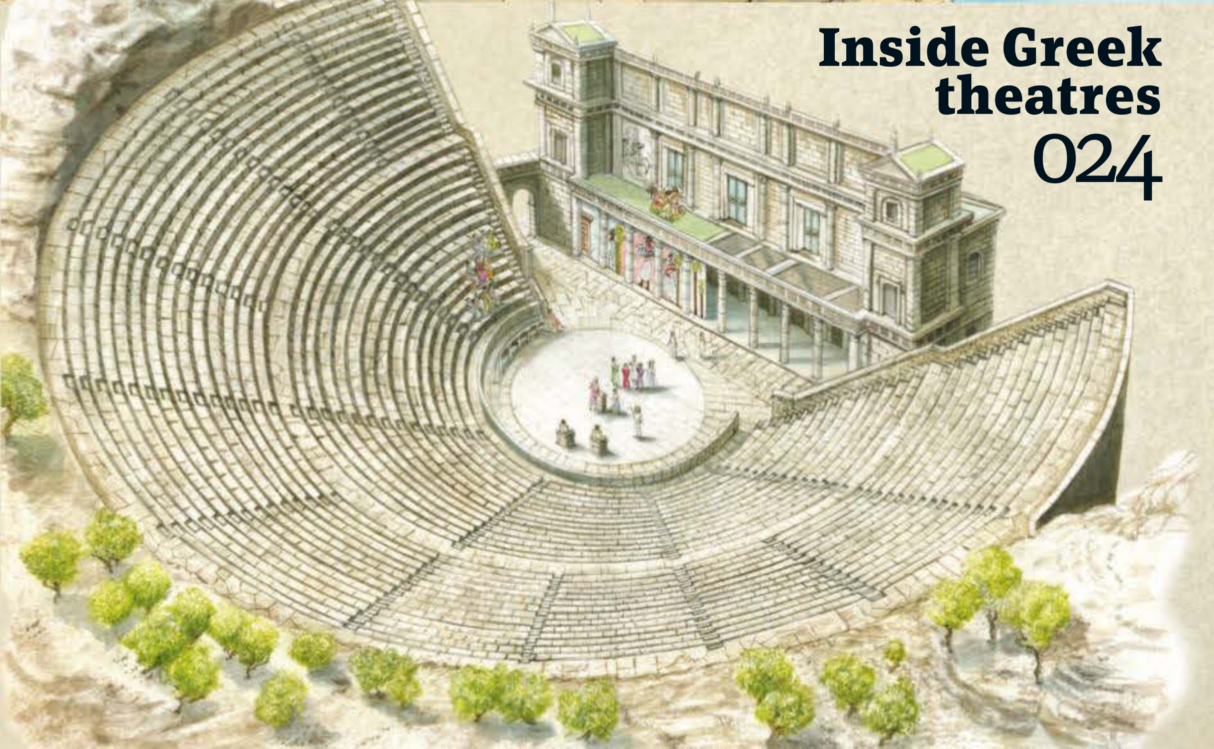

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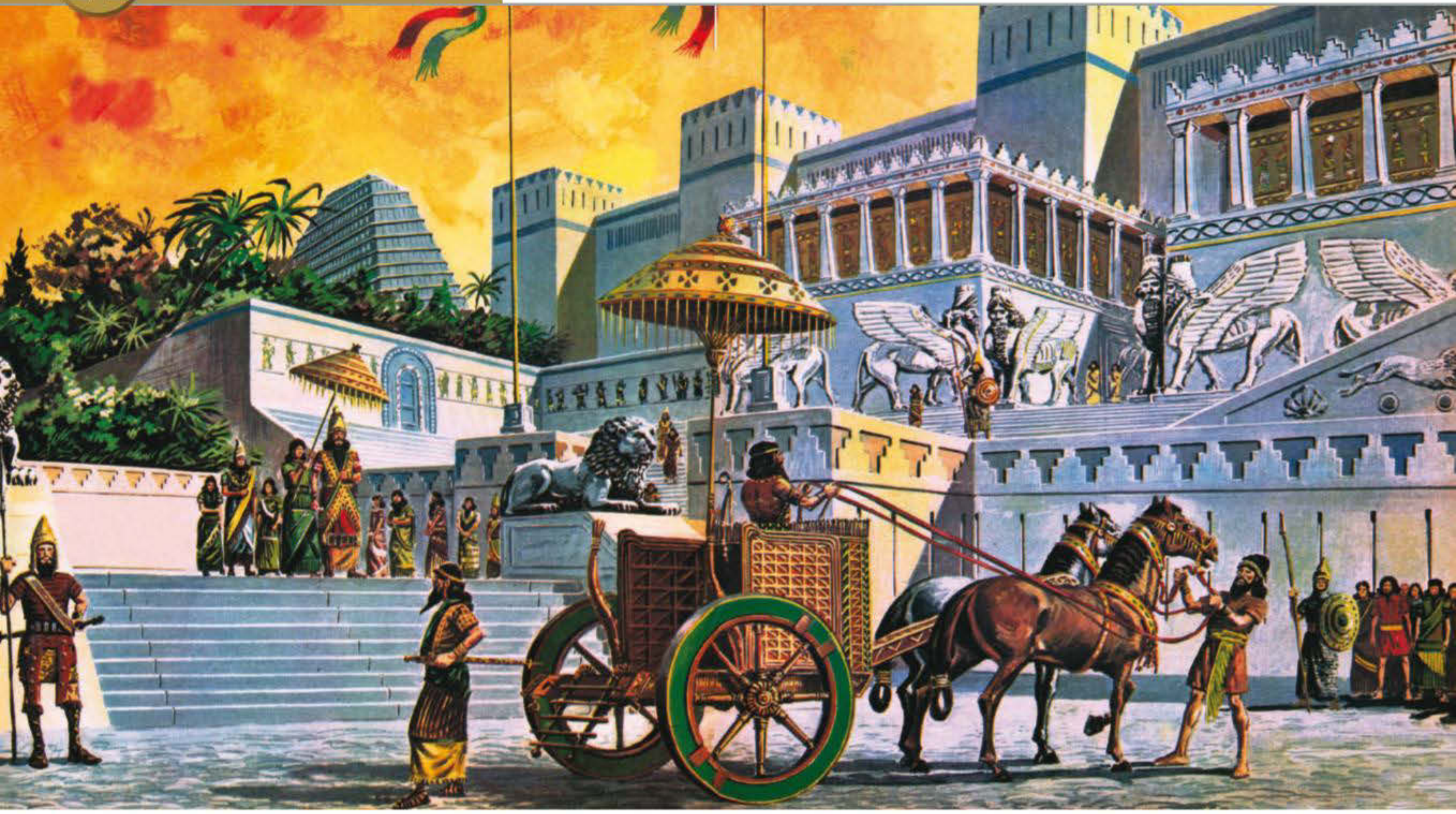


Mesopotamia: The creators of civilisation

Discover how society as we know it began in a small region of modern day Iraq

The ancient region of Mesopotamia has fascinated, enthralled and perplexed historians and scientists for thousands of years. Unlike the ancient empire of Greece, or even Egypt, it was not a united nation. Made up of a vast collection of varied cultures, city-states and beliefs, Mesopotamia was a land of multiple empires and diverse civilisations. It is perhaps thanks to this variety that Mesopotamia gave birth to what we recognise as civilisation today.

The list of Mesopotamian innovations is endless, and it is difficult to contemplate how modern life would be without them. Mesopotamia was home to the first ever cities, writing took form there and the oldest wheeled vehicles in the world were found in Mesopotamian ruins. Animals were domesticated, humanity came on leaps and bounds in agriculture, innovative new tools were crafted, weapons were swung and wine was drunk. Mesopotamians were the first people to study the night sky, track the Moon and declare that there were 60 minutes in an hour, and 60 seconds in a minute.

Mesopotamia was driven by religion, and it was one of the few things that united the lands that made up the region. From this religion sprang customs, moral codes and social hierarchy. In many ways the Mesopotamians were ahead of their time, as women were regarded as individuals in their own right, free to own land, file for divorce and run businesses.

The Mesopotamian version of the Creation story declared that the world was formed when the gods achieved victory over the forces of chaos, and the same could be said in the creation of Mesopotamia itself. With its kings, taxes and trade, it was a triumph of man's ability to conquer and thrive, and it set the blueprints for countless cities, countries and empires that followed.

SUMER

5400 BCE
The city of Eridu is founded; it is considered the first true city in the world.

3600 BCE
Writing first emerges in the form of cuneiform. Reeds are used to make marks in wet clay.

3500 BCE
Religion is first referenced in writing, in the form of Sumerian cuneiform tablets.

2334-2218 BCE
During this period Sumer is conquered by the powerful emperor Sargon the Great and comes under the rule of the Akkadian Empire.

DID YOU KNOW? *Although most of Mesopotamia shared a common religion, each city had its own patron god*

What it was like to live there

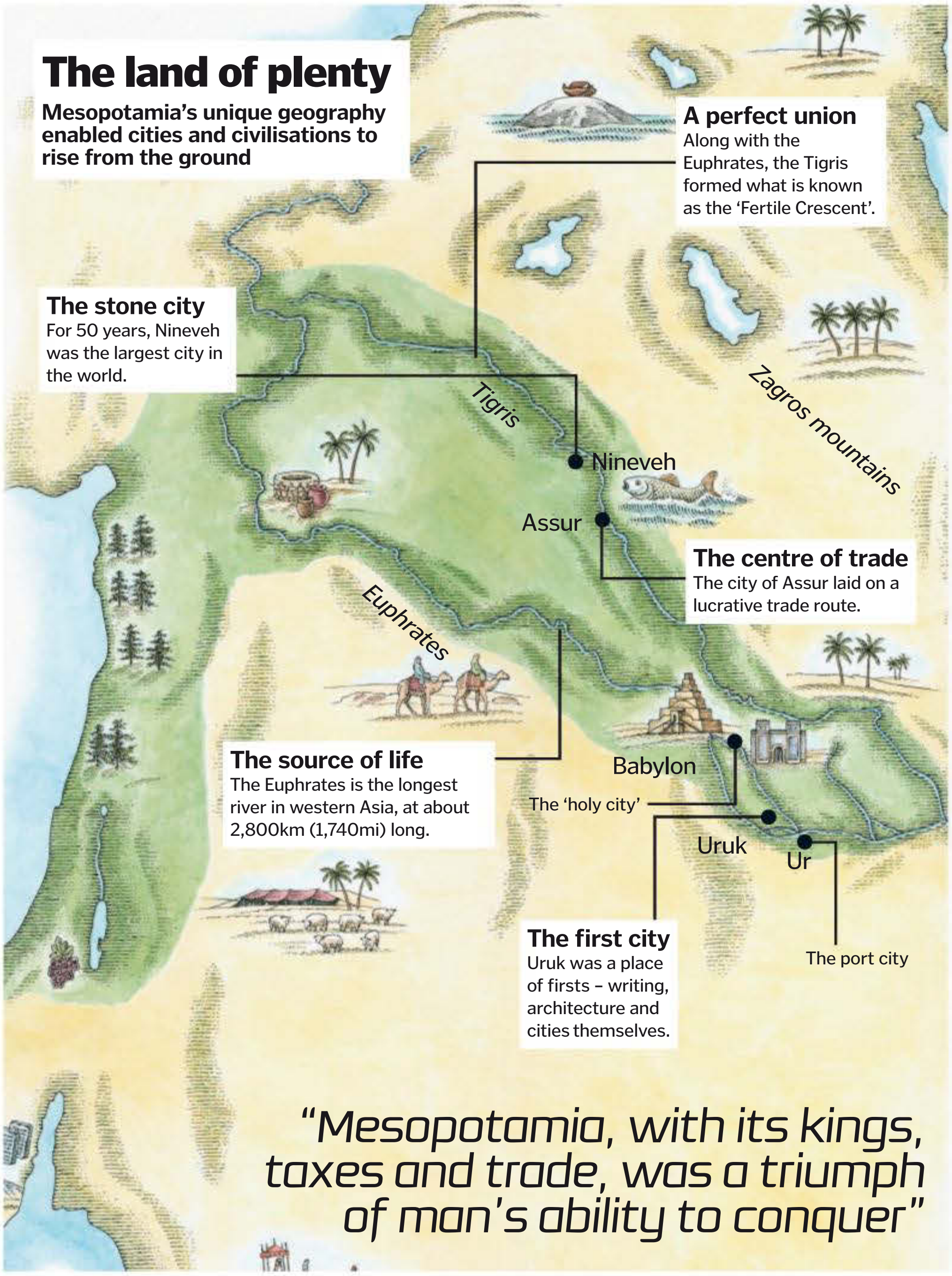
The word 'Mesopotamia' means 'between the rivers', which literally describes the location of the region. Mesopotamia lay between the Tigris and Euphrates rivers, which today flow through modern day Turkey, Iraq and Syria. All the regions of Mesopotamia experienced different geography, which led to variation in how people there lived. Lying between two rivers had some risks as the land was subject to frequent and unpredictable flooding, which could play havoc with farmers' crops. These floods went hand in hand with periods of drought. However, the swelling rivers helped to create very fertile soil that supported plants even with minimal rainfall, and allowed boats to be used as a quick means of transportation. Mesopotamians became skilled farmers and traded their crops for resources they were lacking, such as building materials like wood, metal and stone. The people took advantage of the ready supply of water by building canals to support the trade network and were able to flourish in spite of the lack of natural resources in some areas.

ON THE MAP

Mesopotamia

The land of plenty

Mesopotamia's unique geography enabled cities and civilisations to rise from the ground



A perfect union
Along with the Euphrates, the Tigris formed what is known as the 'Fertile Crescent'.

The stone city
For 50 years, Nineveh was the largest city in the world.

The centre of trade
The city of Assur laid on a lucrative trade route.

The source of life
The Euphrates is the longest river in western Asia, at about 2,800km (1,740mi) long.

The 'holy city'

The first city
Uruk was a place of firsts – writing, architecture and cities themselves.

The port city

> *"Mesopotamia, with its kings, taxes and trade, was a triumph of man's ability to conquer"*

The rise of civilisation

Three of the major cultures that arose in Mesopotamia and influenced society

SUMERIANS

The southernmost region of Mesopotamia, Sumer comprised modern day southern Iraq and Kuwait. Sumer was first inhabited in approximately 4500 BCE, or possibly even earlier. It is in Sumer that the first cities in the world were established, starting with Uruk. Sumerians believed that their cities represented god's triumph over chaos.

BABYLONIANS

Meaning 'gate of the gods', Babylonia lay in central southern Mesopotamia (modern day Iraq). Its earliest days are a mystery lost to rising sea levels, but from 1792 BCE the famous king Hammurabi came into power and the city of Babylon – built upon the Euphrates river – became the beating heart of Mesopotamia.

ASSYRIANS

Located in the Near East, the ancient kingdom of Assyria comprised regions of Iraq, Syria and Turkey. It drove technological, scientific and warfare developments in Mesopotamia. The Assyrian empire gradually expanded to unite most of the Middle East, increasing their power and wealth to become a formidable force.

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2150-1400 BCE
The Epic of Gilgamesh is written during this time. This famous poetic work stands as one of the oldest pieces of western literature in existence.

2100 BCE
The Sumerian King List is created, establishing the idea of kingship as a divine institution.

1800 BCE
All the cities of Sumer, and of Mesopotamia, are united by Hammurabi, who makes Babylon his capital.

1750 BCE
A combination of invasion, migration and the sacking of Ur brings an end to the Sumerian civilisation.

The world's first cities

With its reliable source of food, people gathered in Mesopotamia and formed the very first cities

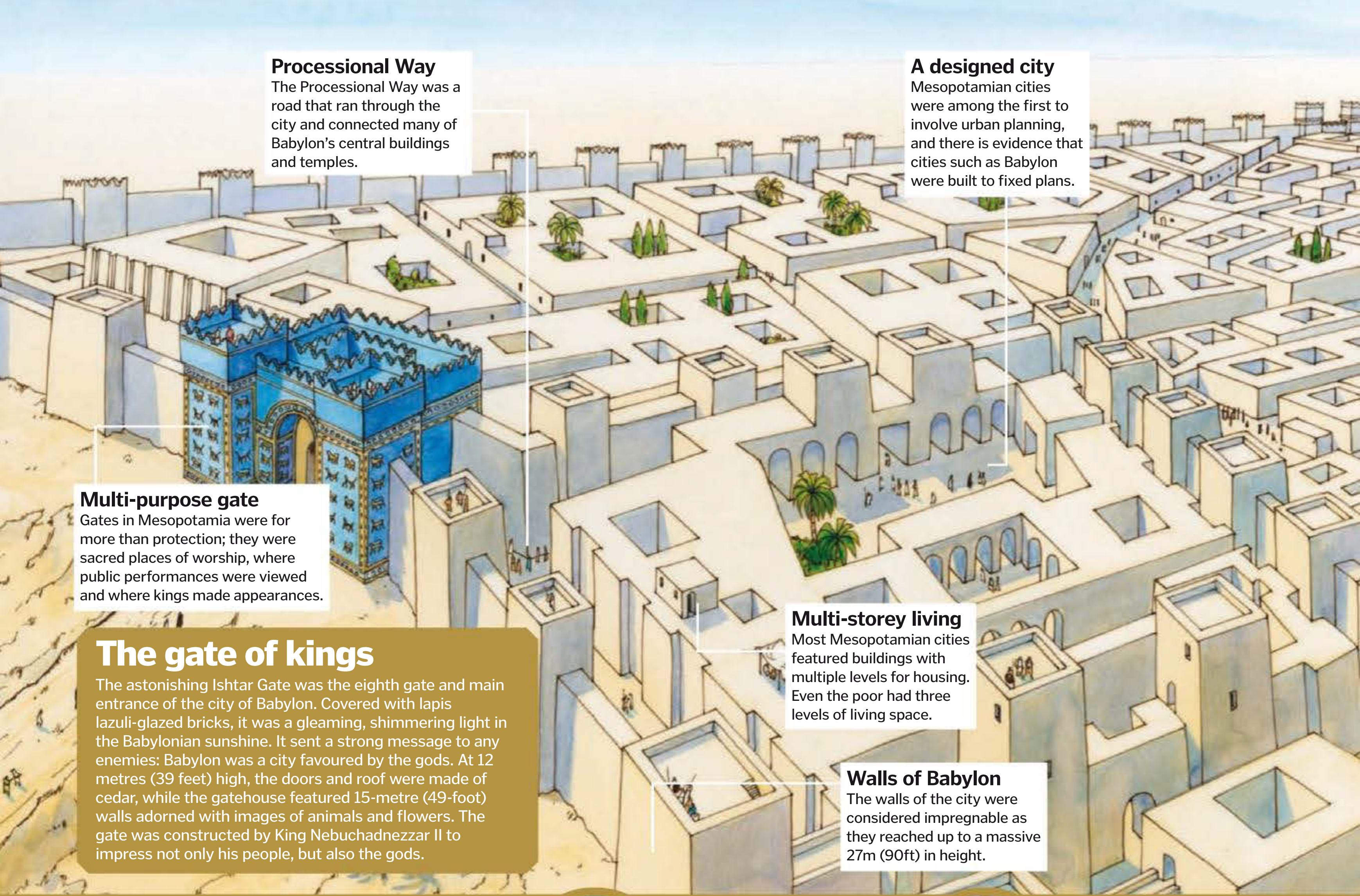
Mesopotamia was home to some of the very first cities in existence, leading many to link it to the birth of true civilisation. The origin of these cities is still unknown today, although many theories exist. One suggestion is that the development and building of temples created a place where people would gather, and thus served as points of contact between different groups of people.

Others believe that people sought sanctuary from natural disasters. As the Mesopotamians were able to develop technology to help them control the nearby rivers, such as levees, they could ensure a good crop. They had no need to be nomadic, and were able to settle in one place comfortably. It is for this reason that all the early cities were built along the two major rivers.

From the moment the Sumerians began to form these cities, it forever altered human history. People went from being ruled by nature, to attempting to control it and make it work for them. By 4500 BCE the first recorded city rose in the form of Uruk. However, the only urban structure at this point was the temple, which regulated all economic and social matters.

The central purpose of these early cities was to help regulate trade, as southern Mesopotamia was reliant on outside resources. This need encouraged the spread of urbanisation. However, communication between the cities was difficult, so each city developed into an individual city-state. This led to territorial disputes and, inevitably, war.

In order to keep their cities protected, the Mesopotamians built fortifications, and walled cities rose. Migration to these cities increased, and more buildings were erected. Cities gradually expanded and rulers were proclaimed, who then began looking outwards for trade and conquest.



Processional Way
The Processional Way was a road that ran through the city and connected many of Babylon's central buildings and temples.

A designed city
Mesopotamian cities were among the first to involve urban planning, and there is evidence that cities such as Babylon were built to fixed plans.

Multi-purpose gate
Gates in Mesopotamia were for more than protection; they were sacred places of worship, where public performances were viewed and where kings made appearances.

Multi-storey living
Most Mesopotamian cities featured buildings with multiple levels for housing. Even the poor had three levels of living space.

Walls of Babylon
The walls of the city were considered impregnable as they reached up to a massive 27m (90ft) in height.

The gate of kings

The astonishing Ishtar Gate was the eighth gate and main entrance of the city of Babylon. Covered with lapis lazuli-glazed bricks, it was a gleaming, shimmering light in the Babylonian sunshine. It sent a strong message to any enemies: Babylon was a city favoured by the gods. At 12 metres (39 feet) high, the doors and roof were made of cedar, while the gatehouse featured 15-metre (49-foot) walls adorned with images of animals and flowers. The gate was constructed by King Nebuchadnezzar II to impress not only his people, but also the gods.

BABYLONIA

1894 BCE
The first Babylonian dynasty emerges; this Amorite dynasty forms a small kingdom including the city of Babylon.

1792 BCE
Hammurabi begins his reign as ruler of Babylon. He transforms it from a tiny town to a powerful city.

1792-1750 BCE
During his reign, Hammurabi introduces some of the earliest examples of laws in the form of the Code of Hammurabi.

1755 BCE
Hammurabi conquers and unites Mesopotamia under his rule, and Babylon becomes known as a holy city.

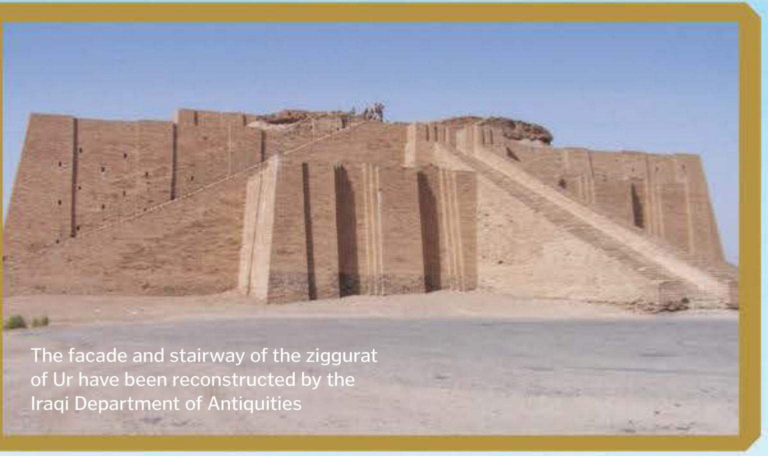
DID YOU KNOW? *No trace of Babylon's famous 'hanging gardens' remains; some experts believe they were in Nineveh instead*

Towering temples

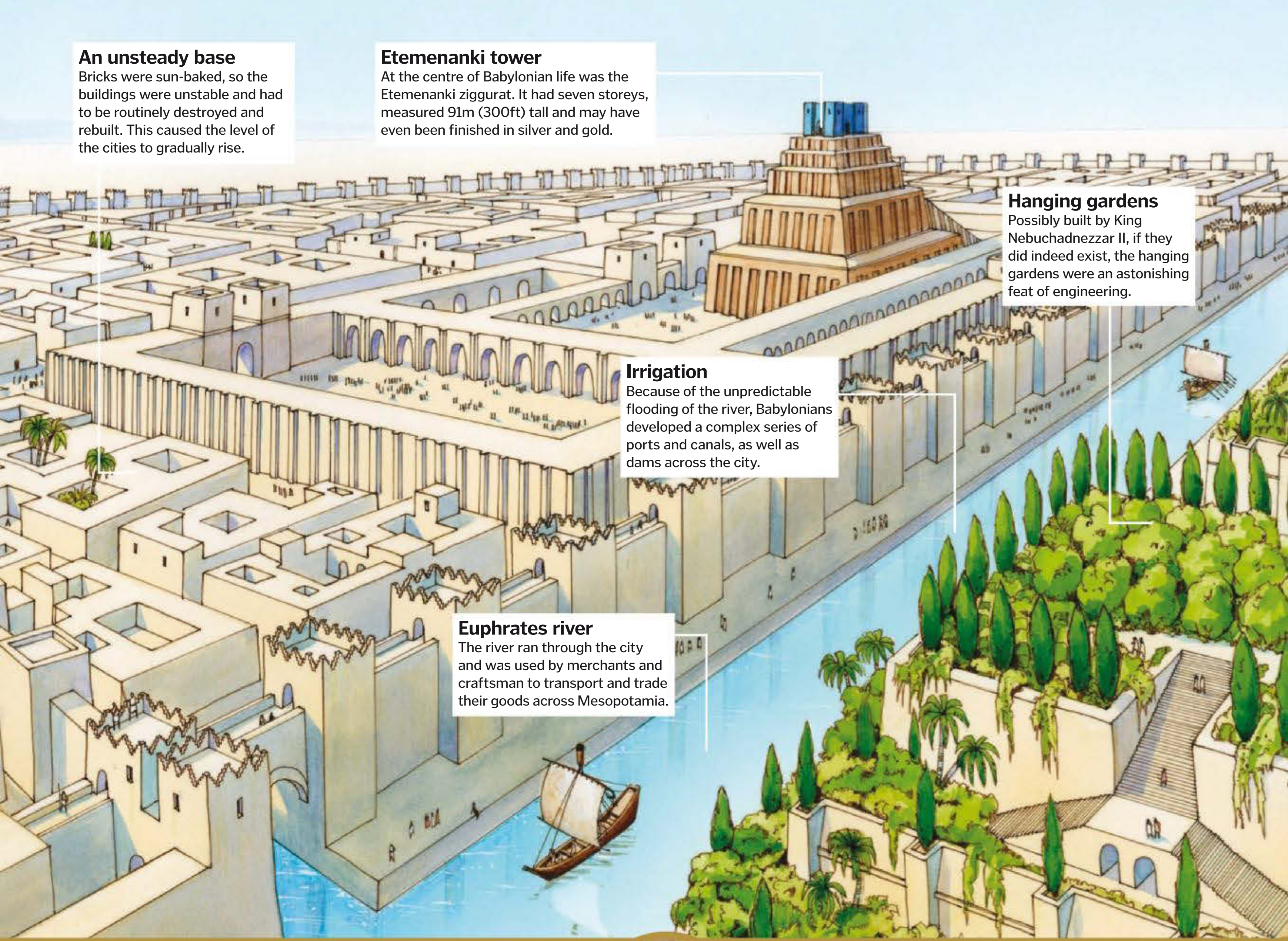
Ziggurats were temples built on high, stepped platforms. Although they originated in Sumerian cities in 2000 BCE, they gradually spread to all of Mesopotamia, including Babylonia and Assyria. The stepped towers were mainly constructed from sun-dried bricks layered between reeds. It is believed that many ziggurats featured a shrine at the top, but no examples of this remain.

Although their exact purpose cannot be verified, it is known that ziggurats were linked to religion, and each ziggurat was connected to large temple complexes. There was a belief in Mesopotamia that the gods resided in the Eastern mountains; therefore building high temples would more closely connect the people with god, linking heaven with Earth.

A practical purpose of the high platforms was to escape any rising floodwater that rushed into the lowlands. The structure of the ziggurat, which was accessible only by three stairways, also ensured that the rituals conducted within remained secret and sacred.



The facade and stairway of the ziggurat of Ur have been reconstructed by the Iraqi Department of Antiquities



An unsteady base

Bricks were sun-baked, so the buildings were unstable and had to be routinely destroyed and rebuilt. This caused the level of the cities to gradually rise.

Etemenanki tower

At the centre of Babylonian life was the Etemenanki ziggurat. It had seven storeys, measured 91m (300ft) tall and may have even been finished in silver and gold.

Hanging gardens

Possibly built by King Nebuchadnezzar II, if they did indeed exist, the hanging gardens were an astonishing feat of engineering.

Irrigation

Because of the unpredictable flooding of the river, Babylonians developed a complex series of ports and canals, as well as dams across the city.

Euphrates river

The river ran through the city and was used by merchants and craftsman to transport and trade their goods across Mesopotamia.

Circa 1750 BCE

Babylonian mathematicians introduce the concept of place value in numbers. Astronomers also name the planets and constellations.

1595 BCE

Babylon is sacked by the Hittite king Mursili I. This marks the beginning of the Babylonian 'dark ages'.

1595–1155 BCE

The Kassite dynasty rules over Babylonia. They rename Babylon 'Kar-Duniash' but it continues to serve as the capital of the kingdom.

1225 BCE

The Assyrian ruler Tukulti-Ninurta I destroys the armies of Babylon and sacks the city. He goes on to become king.

Seven ways Mesopotamia changed the world

The phrase 'the foundations of civilisation' is often used while talking about Mesopotamia. But what exactly does this mean? Is civilisation simply people living together, or does it involve more? Agriculture had emerged by 8000 BCE, and art was produced for thousands of years before Mesopotamia rose. However, Mesopotamia took these aspects of human culture and transformed them into civilisation as we know it today.

Brought together by a common goal – to find food – the Mesopotamians developed some of the earliest writing known to man, borne out of necessity to record accounts and crop yields. However, it later developed to represent more abstract ideas. As people were gathered together, spiritual practices were also refined, and the population began to share a common belief system. With this established, the priests, who claimed to be able to communicate with the gods, took their place at the top of the social hierarchy, and slowly a class system developed. This emphasis on religion inspired moral codes, which led to formal rules and, in turn, punishment for those who disobeyed.

A steady food supply meant the Mesopotamians could pursue other aspects of life, such as technology and science. They made ground-breaking advancements in the areas of mathematics and medicine. However, this social structure also revealed the darker aspects of humanity, such as war, slavery and expansion, and with so many people gathered together, diseases spread rapidly.

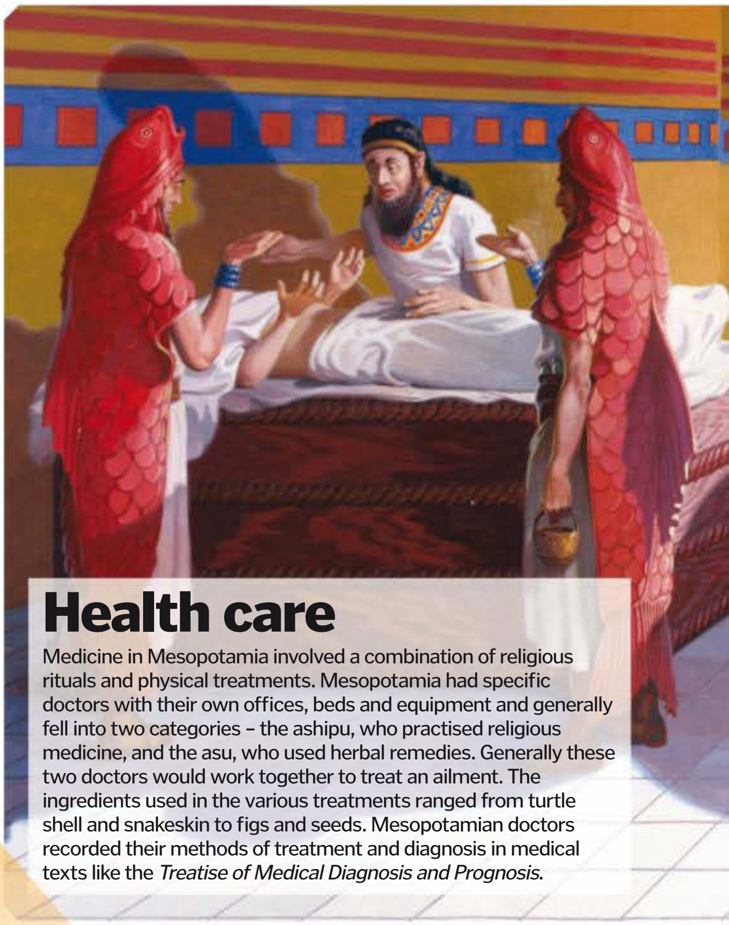
As the civilisation developed, it inevitably had an influence on other cultures. It is believed that Babylonian astronomy influenced Greece, India and even China. The early Mesopotamian codes of laws also had a profound effect on lawmaking in the Near East, and the introduction of taxes and a standing army influenced countries worldwide. In fact, historians are still exploring the huge impact that Mesopotamia had on the ancient world, and the world we live in today.

The creation of writing

Writing began in Mesopotamia towards the end of the 4th millennium BCE as a way to record crucial information about crops and taxes in pictorial form. These early tablets developed into a script, which bears close resemblance to writing today. This system of writing is commonly known as cuneiform and comprised of wedge shaped marks in clay. Gradually the number of characters used in cuneiform decreased from 1,000 to around 400, which ensured more clarity in the script. By 2500 BCE cuneiform was advanced enough to portray emotions such as fear and hope.

The word cuneiform itself simply means 'wedge-shaped'

The remains of the Code of Hammurabi were discovered in 1901 in excellent condition



Health care

Medicine in Mesopotamia involved a combination of religious rituals and physical treatments. Mesopotamia had specific doctors with their own offices, beds and equipment and generally fell into two categories – the ashipu, who practised religious medicine, and the asu, who used herbal remedies. Generally these two doctors would work together to treat an ailment. The ingredients used in the various treatments ranged from turtle shell and snakeskin to figs and seeds. Mesopotamian doctors recorded their methods of treatment and diagnosis in medical texts like the *Treatise of Medical Diagnosis and Prognosis*.

Thou shalt obey

Law codes as we know them were first seen in Mesopotamia. One of the earliest is the Code of Hammurabi, which features 282 laws dealing with a huge variety of issues in great detail, from marriage to theft. For example, if a man rents a boat to a sailor and it is wrecked, the sailor has to give the man a new boat. Although it is the most well-known, the Code of Hammurabi was pre-dated by other law codes, such as the code of Lipit-Ishtar and those written by the Sumerian king Ur-Nammu, who described the purpose of his laws as protecting the weak from the mighty.

ASSYRIA

2600 BCE
The city of Ashur, capital of Assyria, is founded, along with other Assyrian cities.

1813–1776 BCE
Shamshi-Adad I rules Assyria. He expands the empire, secures Assyria's borders and builds up a powerful army.

1472 BCE
The kingdom of Mitanni, a powerful northern Mesopotamian state, annexes Assyria and the land loses its independence.

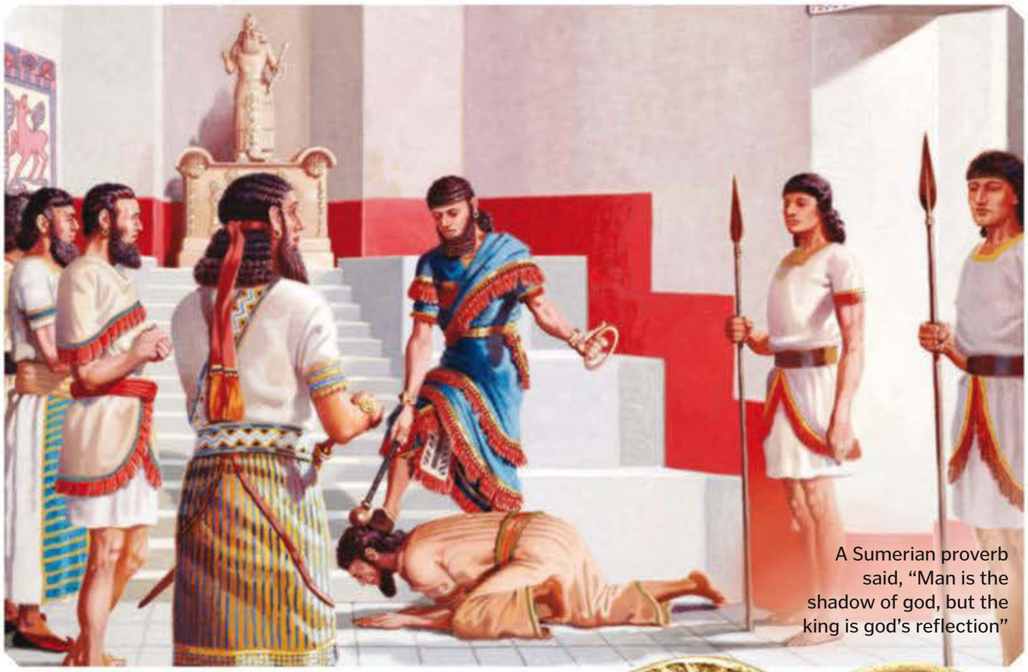
1365–1330 BCE
Ashur-uballit I defeats the Mitanni, and under his leadership, Assyria develops as a powerful and rapidly expanding empire.

1244–1208 BCE
The warrior king, Tukulti-Ninurta I, reigns. Assyria expands to its greatest extent and defeats the ruler of Babylonia.

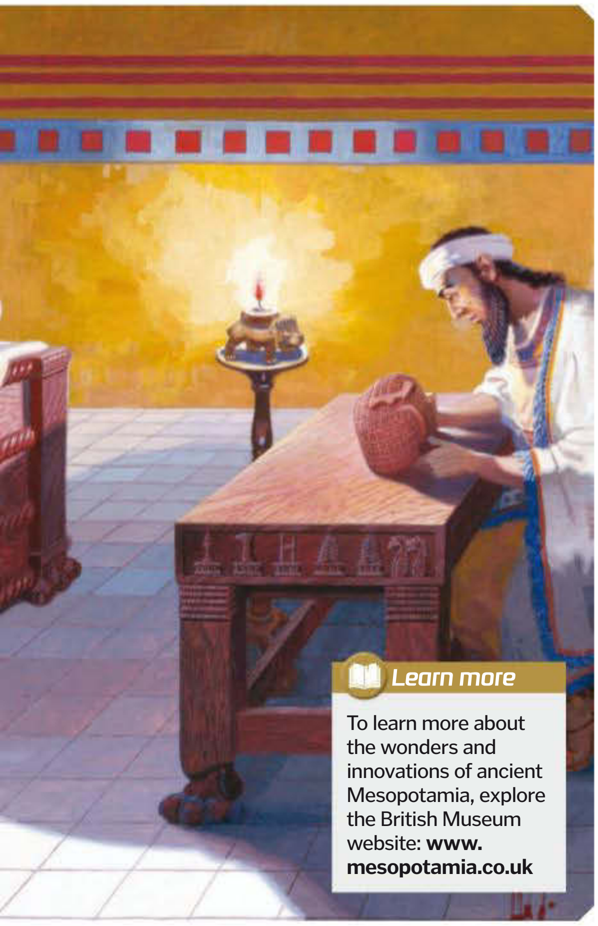
DID YOU KNOW? *Assyrian warfare was brutal; the words 'I destroyed, devastated and burned with fire' appeared on inscriptions*

Only the strong shall lead

Mesopotamia was made up of several city-states which each had their own leaders and government, with kings ruling over individual regions. This led to a lot of internal fighting between different kings for land and resources. The first kings were the leaders of armies, who then went on to continue to lead during peacetime. Because of the strong emphasis on religion, the kings often served as high priests and therefore were linked to the divinity of god, and claimed to be god's representatives on Earth. Some of these kings, such as Sargon, sought to unite many of the city-states under one leader and capital.



A Sumerian proverb said, "Man is the shadow of god, but the king is god's reflection"



Learn more

To learn more about the wonders and innovations of ancient Mesopotamia, explore the British Museum website: **www.mesopotamia.co.uk**

Mesopotamian money

Mesopotamians used silver rings thousands of years before the first coins were made. In around 2500 BCE a 'shekel' of silver became the currency of Mesopotamia, with one month of labour being worth one shekel, and a slave worth between ten and 20. Prior to this, clay tokens in a variety of sizes and shapes were used for trade and barter. There were at least 16 different types of these tokens that represented various things, such as rope, sheep's milk, perfume and honey.

This Carthaginian shekel from 310-290 BCE is similar to the Mesopotamian shekel

The Standard of Ur, an artefact dating from around 2600 BCE, depicts wheeled chariots being used in battle

The basis of time

The Mesopotamians were trailblazers in their concept of time. They were the first in recorded history to use a base 60 numerical system that led to our 60-second minutes and 60-minute hours. Many believe that this helped the Babylonians make such impressive advances in mathematics, as 60 has many divisors. They also used a lunar calendar, which comprised 12 lunar months, at an average of 29.5 days each. This left the Mesopotamians short by around 11 days a year, so they added seven months in each 19-year period to keep the seasons aligned.

The Royal Game of Ur, one of the oldest in the world, was played with early Mesopotamian mathematics

A wheely late invention

The wheel was actually invented at a surprisingly late point of human history, with the oldest example from Mesopotamia dating to 3500 BCE, in the Bronze Age. It is likely that the wheel was developed individually by different cultures around the same time. Evidence shows that Mesopotamians used this invention for pottery first, before adapting the design for transport with chariots. Wheels did offer advantages to transportation, but they took a great deal of time to make as smooth as possible, so sledges were still commonly used alongside the wheel.

1000 BCE

Assyria establishes the first cavalry force. As this is before the invention of saddles, the warriors ride bareback.

668-627 BCE

During his reign, King Ashurbanipal establishes a huge library, housing a collection of thousands of clay tablets.

612 BCE

Many Assyrian cities, including Ashur and Nineveh, are sacked and destroyed by a combined force of Medes, Persians and Babylonians.

© Alamy

How Vesuvius destroyed Pompeii

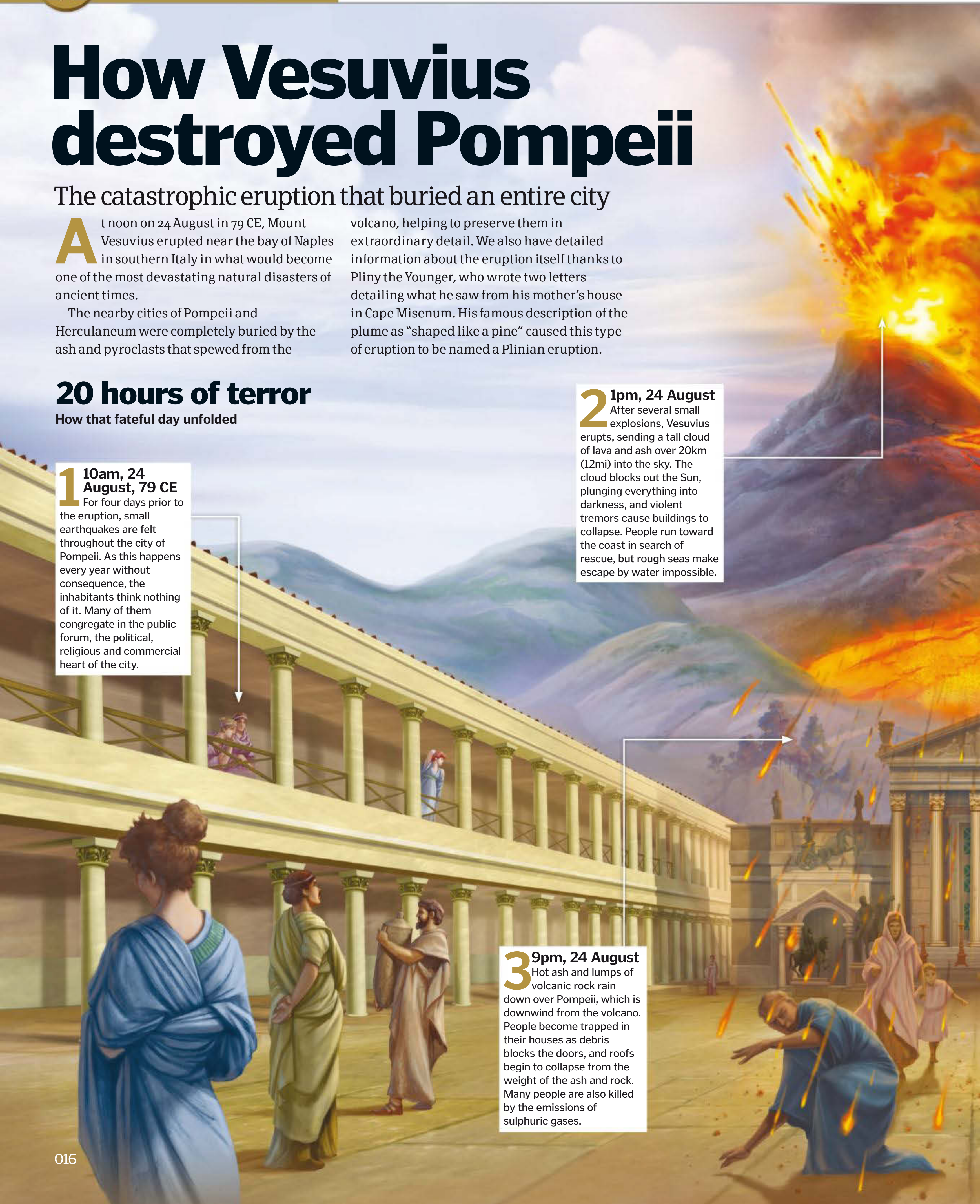
The catastrophic eruption that buried an entire city

At noon on 24 August in 79 CE, Mount Vesuvius erupted near the bay of Naples in southern Italy in what would become one of the most devastating natural disasters of ancient times.

The nearby cities of Pompeii and Herculaneum were completely buried by the ash and pyroclasts that spewed from the volcano, helping to preserve them in extraordinary detail. We also have detailed information about the eruption itself thanks to Pliny the Younger, who wrote two letters detailing what he saw from his mother's house in Cape Misenum. His famous description of the plume as "shaped like a pine" caused this type of eruption to be named a Plinian eruption.

20 hours of terror

How that fateful day unfolded

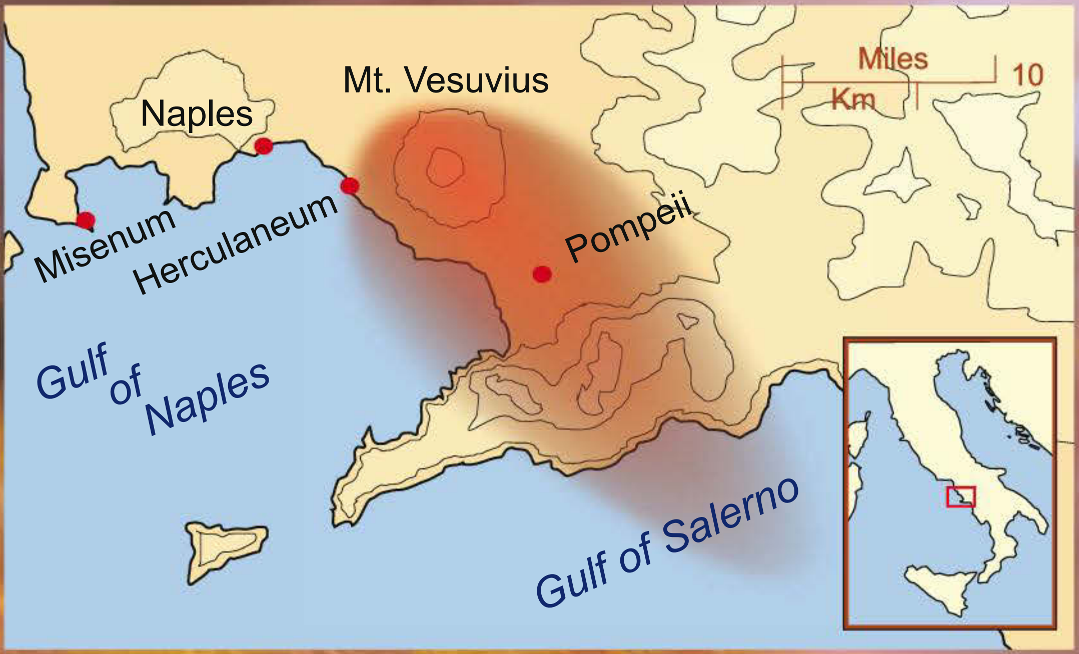


1 10am, 24 August, 79 CE
For four days prior to the eruption, small earthquakes are felt throughout the city of Pompeii. As this happens every year without consequence, the inhabitants think nothing of it. Many of them congregate in the public forum, the political, religious and commercial heart of the city.

2 1pm, 24 August
After several small explosions, Vesuvius erupts, sending a tall cloud of lava and ash over 20km (12mi) into the sky. The cloud blocks out the Sun, plunging everything into darkness, and violent tremors cause buildings to collapse. People run toward the coast in search of rescue, but rough seas make escape by water impossible.

3 9pm, 24 August
Hot ash and lumps of volcanic rock rain down over Pompeii, which is downwind from the volcano. People become trapped in their houses as debris blocks the doors, and roofs begin to collapse from the weight of the ash and rock. Many people are also killed by the emissions of sulphuric gases.

4 **12am, 25 August** The ash cloud reaches its maximum height of 30km (19mi) and then collapses, sending a pyroclastic surge of hot gas and rock down the volcano's northwest slope toward Herculaneum. Moving up to 700km/h (435mph) and with temperatures up to 400°C (752°F), the surge instantly kills everyone it touches.

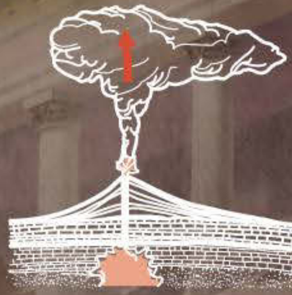


5 **6am, 25 August** As dawn breaks, the cloud collapses for the last time, sending another pyroclastic surge toward Pompeii that kills everyone in its path. By the time the eruption is over, Pompeii is buried underneath 5m (16ft) of volcanic material, while Herculaneum is buried under 20m (66ft).

> *"By the time the eruption is over, Pompeii is buried underneath 5m (16ft) of volcanic material"*

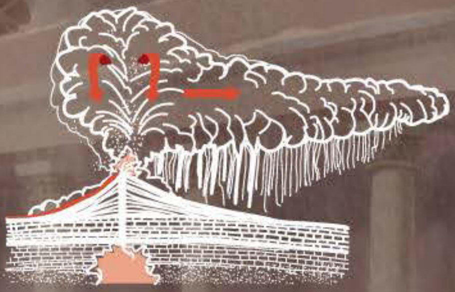
Anatomy of the eruption

Initial explosion



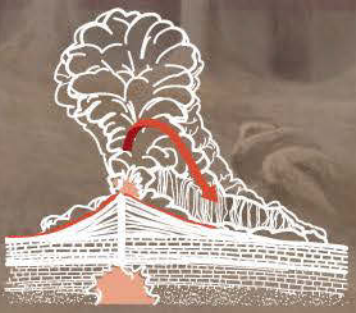
After more than 800 years of inactivity, pressure inside the volcano became too great. The built-up gases burst through the thick layer of lava that had plugged the crater and a column of ash climbs upward.

Spreading cloud



The wind blows the cloud toward the southeast, and it spreads to nearly 100km (60mi) in width from side to side. Ash falls on Pompeii at a rate of 15cm (6in) per hour for an entire day.

Pyroclastic flows



As the ash cloud collapses, volcanic debris rolls down the sides of the volcano toward Herculaneum, which is 6km (3.7mi) away, and Pompeii, which is 10km (6.2mi) away. Anyone in the path of the flow had their body burned to the bone in seconds.

© Solgo

The mystery of Easter Island

Who built the giant heads of Rapa Nui and why?

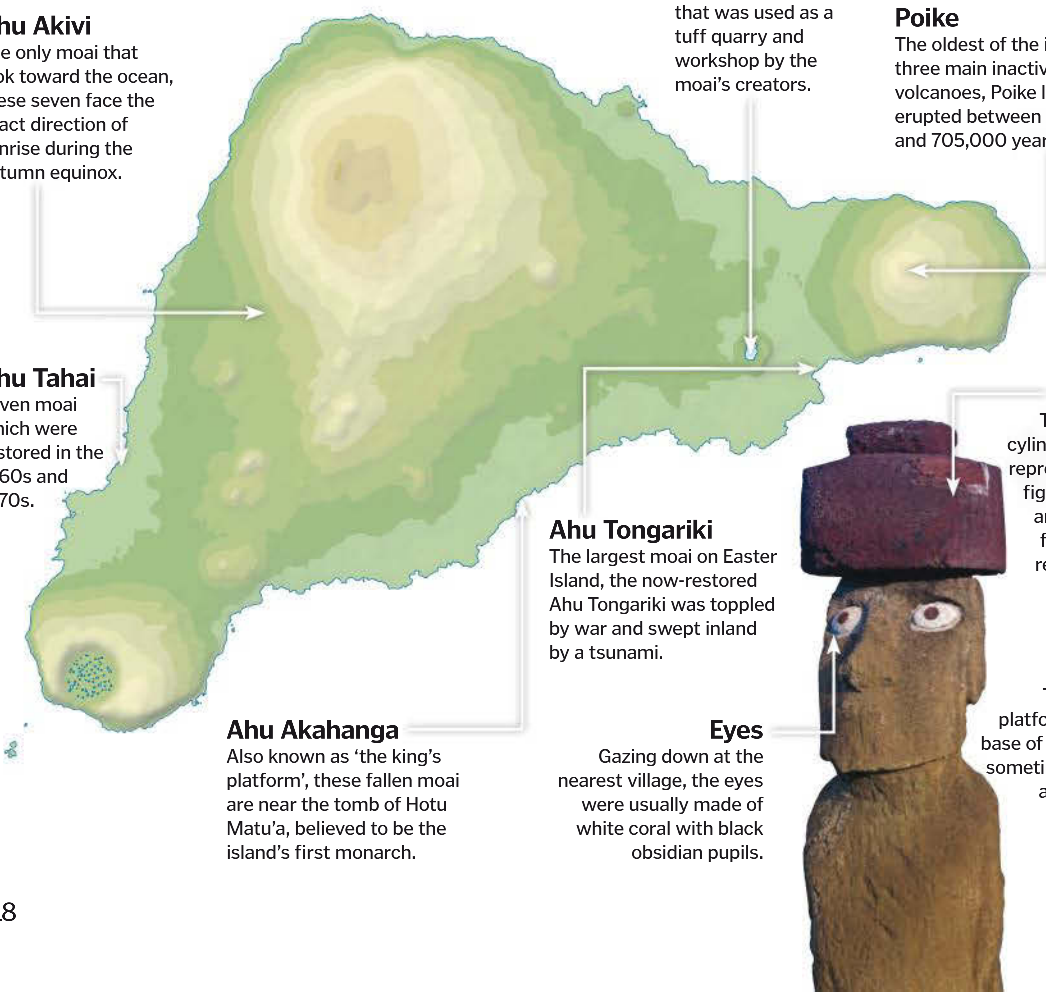
The most easterly island in Polynesia, approximately 3,700 kilometres (2,300 miles) west of South America in the Pacific Ocean, Easter Island could hardly be more remote. Yet this isolated landmass is home to some of the most incredible man-made wonders on Earth – over 887 carved stone heads, called moai, that have seen the entire 166.3-square-kilometre (64.2-square-mile) island, known as Rapa Nui by its population, designated as a UNESCO World Heritage Site.

The origin of these stern-faced monoliths – which average four metres (13 feet) tall and weigh an average of 14 tons – and the society that built them is largely a mystery. What is known is that settlers travelling on wooden outrigger canoes arrived on the island between the 4th and 13th centuries and carved the moai sometime between the 10th and 16th centuries from tuff – a light, porous volcanic rock – and placed them upon platforms called ahu. Some even wear 'hats' of red scoria, representing the topknot hair styles of the Rapa Nui people. The eye sockets are believed to have held coral eyes with either black obsidian or red scoria pupils, while the bodies may have been carved with patterns that mimic the traditional tattoos of the Rapa Nui.

As for why they were carved, it may have been to honour important chieftains or warriors as some of them contained tombs in their ahu, or it may be to offer protection as with only a few exceptions they gaze over nearby villages. Ultimately it's impossible to know for certain. When Dutch explorers arrived on the island on Easter Day in 1722, the islanders that had created these breathtaking monuments had long since been divided by civil wars and many of its moai toppled, leaving only stories preserved in the oral histories of the Rapa Nui people and a forest of impassive stone heads breaking forth from the earth to stare out across the grass.

Treasure Island

The many moai of Easter Island



Ahu Akivi
The only moai that look toward the ocean, these seven face the exact direction of sunrise during the autumn equinox.

Rano Raraku
A volcanic crater that was used as a tuff quarry and workshop by the moai's creators.

Poike
The oldest of the island's three main inactive volcanoes, Poike last erupted between 230,000 and 705,000 years ago.

Ahu Tahai
Seven moai which were restored in the 1960s and 1970s.

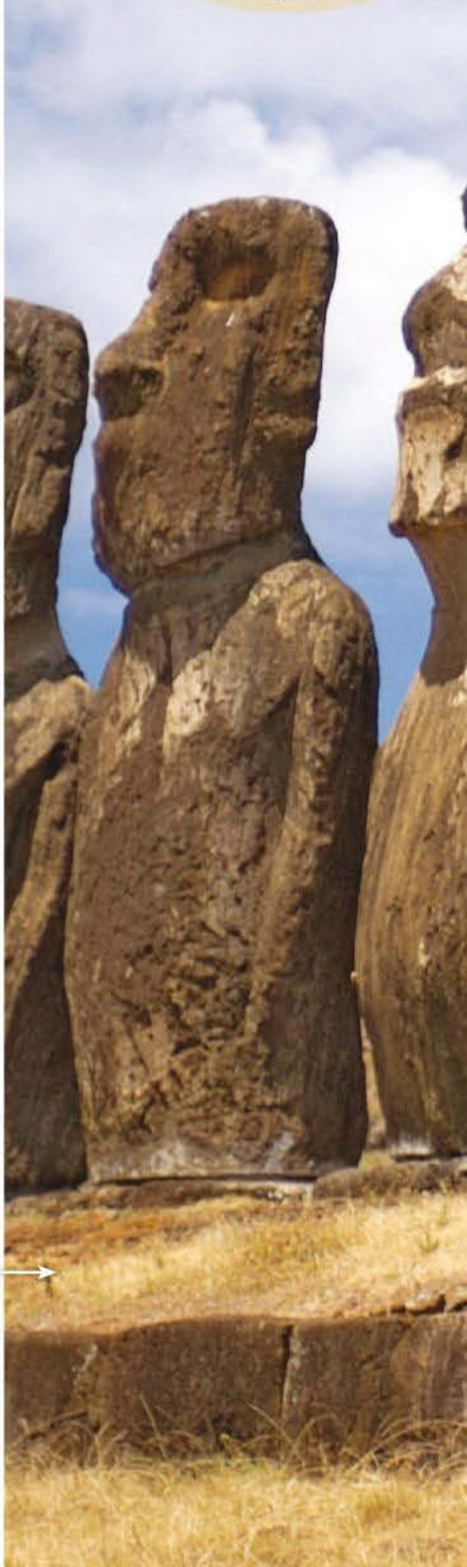
Pukao
The stone cylinders that represent the figure's hair are carved from light red scoria.

Ahu Tongariki
The largest moai on Easter Island, the now-restored Ahu Tongariki was toppled by war and swept inland by a tsunami.

Ahu
The stone platform at the base of the moai, sometimes used as a tomb.

Ahu Akahanga
Also known as 'the king's platform', these fallen moai are near the tomb of Hotu Matu'a, believed to be the island's first monarch.

Eyes
Gazing down at the nearest village, the eyes were usually made of white coral with black obsidian pupils.



DID YOU KNOW? *Swiss author Erich von Däniken speculated the moai were built by aliens; the 'ancient astronaut' hypothesis*

What happened to their creators?

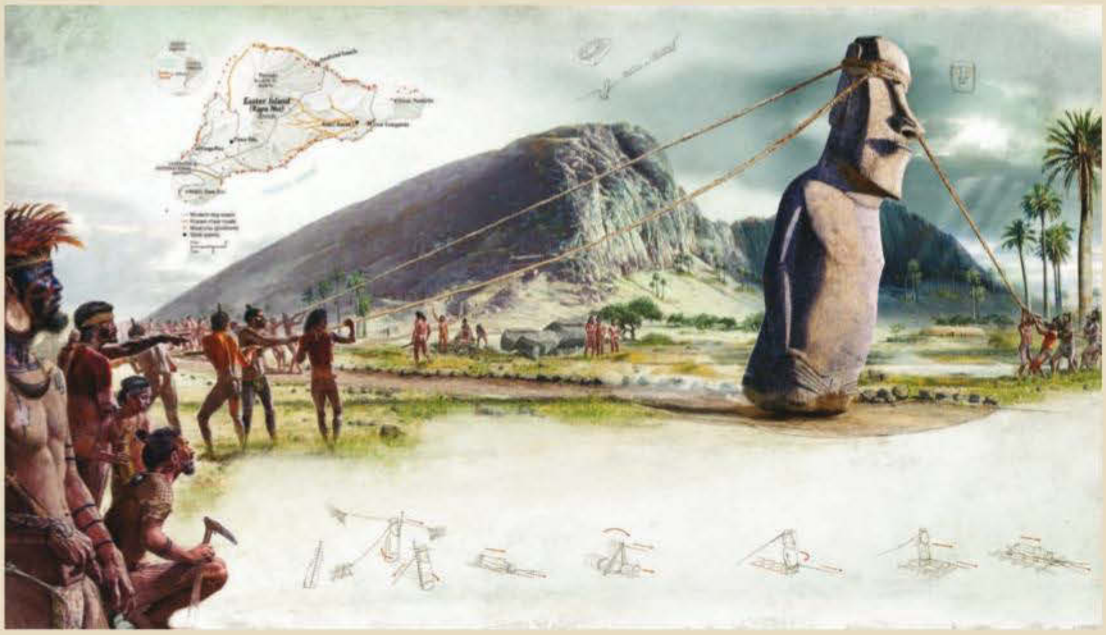
Though largely barren and sparsely inhabited by the time Europeans arrived on Rapa Nui, the island was once heavily forested and home to several now-extinct species of birds before it suffered a mysterious collapse. One theory is that the rats and chickens brought by the original settlers as a source of food laid waste to the island's limited plant life. When the last palm trees were cut down – maybe as late as the 17th century – the Rapa Nui's ability to build boats and fish for food was also restricted. As conflict between tribes for the dwindling resources became inevitable, the population plummeted and some even resorted to cannibalism.

How were they moved?

Though the carvings are impressive, getting them into place suggests a feat of engineering even more so. With no evidence of wheels or cranes – and no large animals to do all the heavy pulling – archaeologists originally believed the moai may have been moved on sledges or wooden rollers as far as 18 kilometres (11 miles) from the quarry.

Though some scholars still support this, a more recent theory is that the curved base of the moai was designed for them to be 'rocked' from side to side and then pulled forward by carefully coordinated teams of workers with ropes. Damage to the base during experiments moving replica statues is consistent with flakes of rock found along roadsides on the island.

The debate is still ongoing, but this theory may be the source of Rapa Nui folklore that recalls the statues being commanded to walk by the gods.



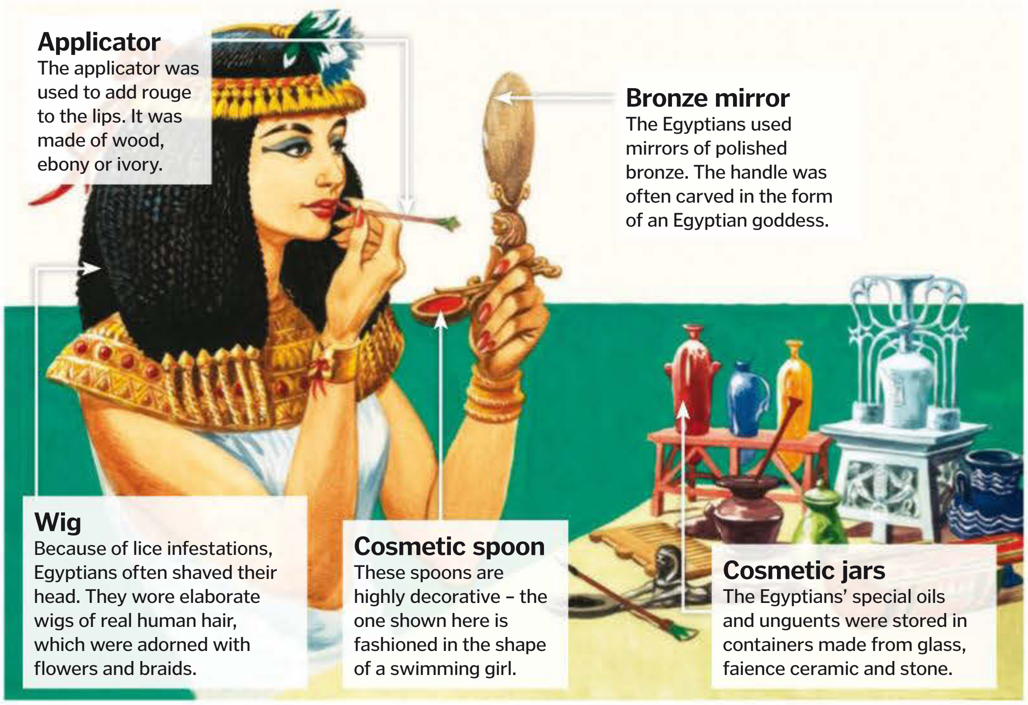
© Credit: National Geographic; Alamy; Thinkstock

Ancient Egyptian cosmetics

Makeup was once an important part of everyday life in Egypt – find out why

In Ancient Egypt, the physical image of an individual often acted as a substitute for the body in the afterlife. Therefore, in funerary paintings, both males and females are portrayed in their best clothes, wigs as well as makeup.

In life, the Egyptians utilised a variety of pigments to adorn the face. The most predominant of these was kohl, which was used to line the eyes. Kohl came from two sources: a green eye paint made of mineral malachite and a black liner derived from galena, a form of lead ore. Women used red ochre to form a light blush for cheeks and lips, while henna was used to paint the nails and dye the hair. Cosmetics were also applied for practical reasons – the military wore it to protect their eyes from the intense glare of the African Sun. Moreover, it had a religious resonance – each day, in the holy sanctuary of the temple, the god was anointed with makeup as a symbol of celestial regeneration.



Applicator
The applicator was used to add rouge to the lips. It was made of wood, ebony or ivory.

Bronze mirror
The Egyptians used mirrors of polished bronze. The handle was often carved in the form of an Egyptian goddess.

Wig
Because of lice infestations, Egyptians often shaved their head. They wore elaborate wigs of real human hair, which were adorned with flowers and braids.

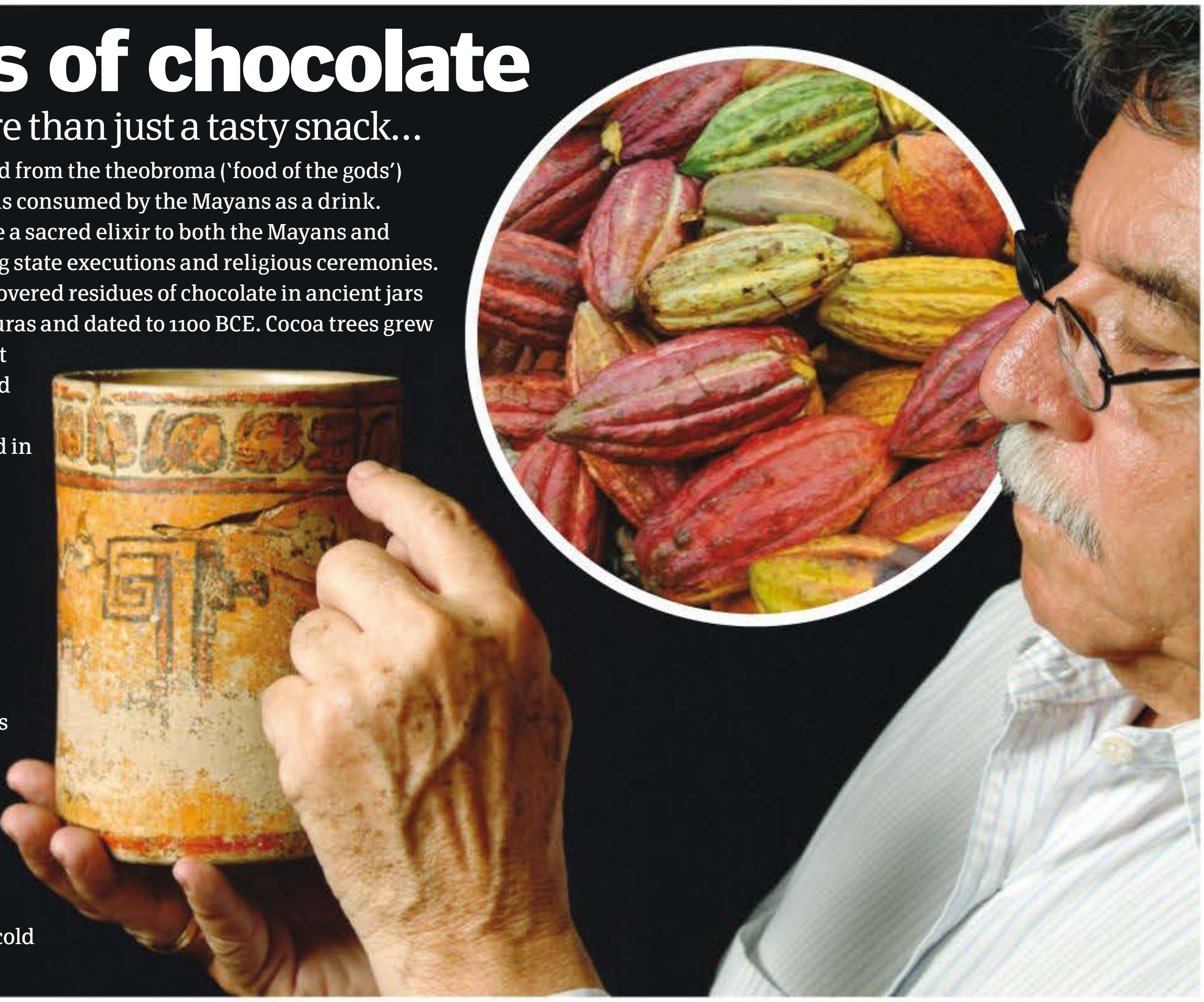
Cosmetic spoon
These spoons are highly decorative – the one shown here is fashioned in the shape of a swimming girl.

Cosmetic jars
The Egyptians' special oils and unguents were stored in containers made from glass, faience ceramic and stone.

Origins of chocolate

Why it was more than just a tasty snack…

Chocolate is derived from the theobroma ('food of the gods') cacao tree and was consumed by the Mayans as a drink. Chocolate became a sacred elixir to both the Mayans and Aztecs; it was used during state executions and religious ceremonies. Archaeologists have discovered residues of chocolate in ancient jars that were found in Honduras and dated to 1100 BCE. Cocoa trees grew in abundance throughout the Mayan territories, and by 600 CE their pods (pictured) were processed in order to produce a frothy, bitter drink. The Mayans blended their chocolate with spices like chilli pepper and vanilla; once consumed they were believed to ward off tiredness. Evidence suggests that cocoa beans were also ground to a powder. During this process, other ingredients could be added – in this instance, the resulting powder was mixed with cold water to create porridge.



© Look and Learn; Corbis

DID YOU KNOW? *Entire military units were punished by selecting one-tenth of their soldiers at random for execution*

Roman crime and punishment

Hold on to your coin purse and take a trip down the mean streets of ancient Rome

During the first century CE it is estimated that the city of Rome supported 1 million inhabitants. As with any city, densely populated areas with wide class divides can easily become criminal hotspots.

The foundation of Roman law was known as the Twelve Tables, a dozen rules that every citizen had to obey. The Twelve Tables were so important that schoolchildren learnt to read and write by copying laws down and reciting them.

While some soldiers, volunteers and officials were tasked with keeping the peace, the city had no dedicated police force, so upholding the law could be difficult. Harsh punishments were the main deterrents, ranging from a brutal beheading to elaborate public executions at the Colosseum.

The crimes committed and punishments received often depended on the social standing of the accused. High-class citizens convicted of major crimes were often given the option of exile rather than execution. Slaves, on the other hand, were punished harshly. If one slave was caught committing a crime, it was not uncommon for all the other slaves of the household to be punished as well, to discourage uprisings.

The Praetorian Guard was very influential and played a role in the removal and accession of several emperors

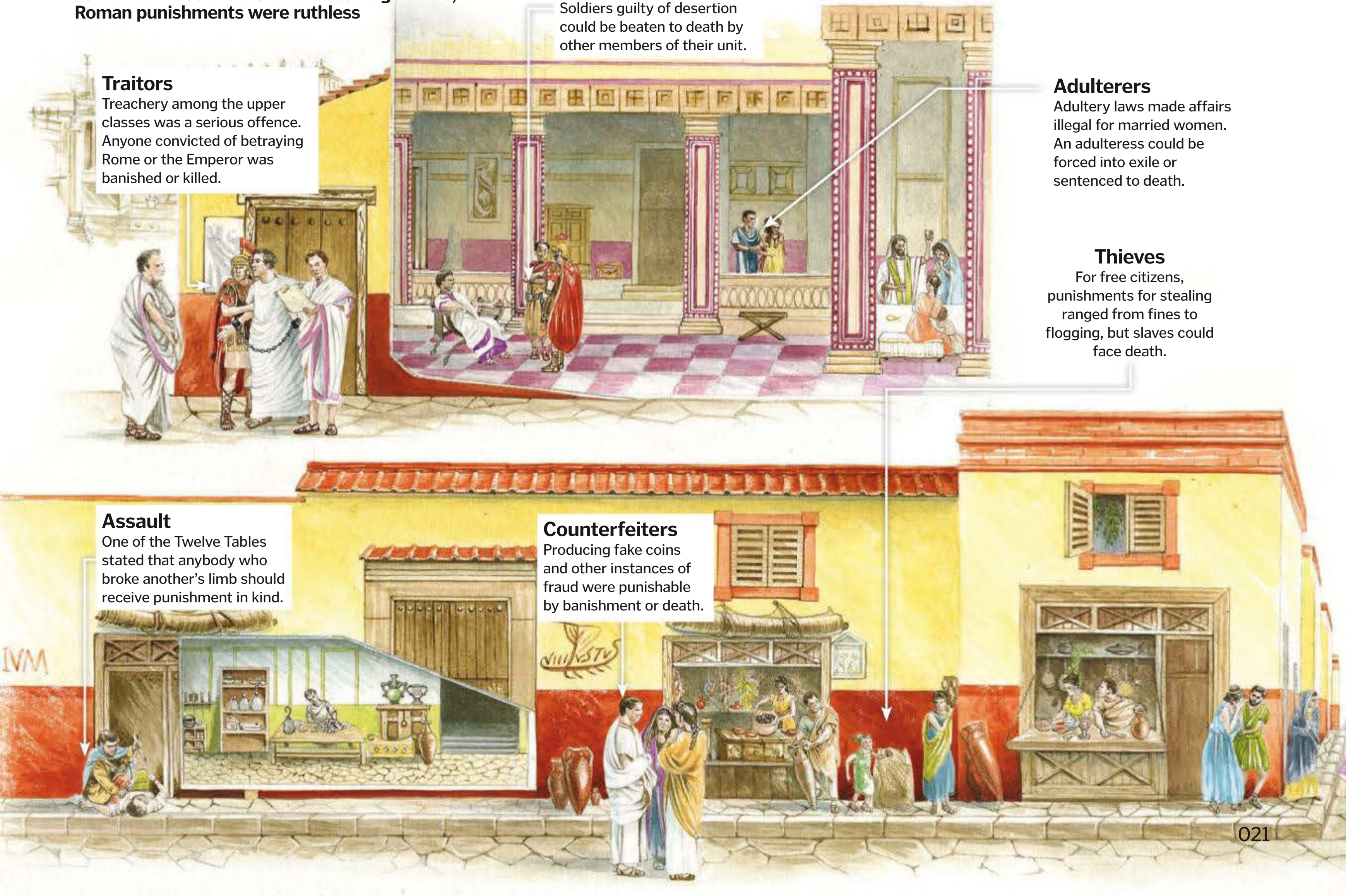
Keeping the peace

While there was no official police force in Ancient Rome, leaders enlisted some groups to be in charge of crime prevention. Vigiles were volunteers who performed the dual role of police and firefighters. They patrolled the city at night, scouting for potential criminals or runaway slaves, while also helping to extinguish fires. Urban cohorts were soldiers that played the role of riot police. Rather than patrolling the streets, they were only summoned if a situation got out of hand.

The Praetorian Guard was responsible for protecting the Emperor, like bodyguards. Despite only having a single person to protect, at times the Praetorian Guard consisted of over 1,000 men. None of these groups were tasked with catching criminals after a crime was committed. If Roman citizens were victims of crime, it was their responsibility to catch the perpetrator and take him or her to the magistrate for a trial.

Criminals of Rome

To maintain social order and discourage crime, Roman punishments were ruthless



Deserters
Military discipline was severe. Soldiers guilty of desertion could be beaten to death by other members of their unit.

Traitors
Treachery among the upper classes was a serious offence. Anyone convicted of betraying Rome or the Emperor was banished or killed.

Adulterers
Adultery laws made affairs illegal for married women. An adulteress could be forced into exile or sentenced to death.

Thieves
For free citizens, punishments for stealing ranged from fines to flogging, but slaves could face death.

Assault
One of the Twelve Tables stated that anybody who broke another's limb should receive punishment in kind.

Counterfeiters
Producing fake coins and other instances of fraud were punishable by banishment or death.

Ancient Peruvian burials

The Paracas people predate the Incas, but even more unbelievable is what they left behind

Though some Paracas were found in expensive clothing and jewellery, others were far more simply dressed, and presumably of a lower social status

For ancient civilisations, giving the dead a proper burial was absolutely essential to ensure the deceased could pass into the next life with safety, dignity and even a bit of style. In ancient, pre-Inca Peru, funeral arrangements took on a bizarre fashion.

The Paracas people lived from around the 8th century BCE until the 3rd century CE. For at least some of this time, they buried their dead wrapped in layers of textiles woven from alpaca wool and cotton. Each piece was decorated with embroidered patterns of animals and humans, and dyed in many colours. The deceased sat within, usually north-facing, in a small basket.

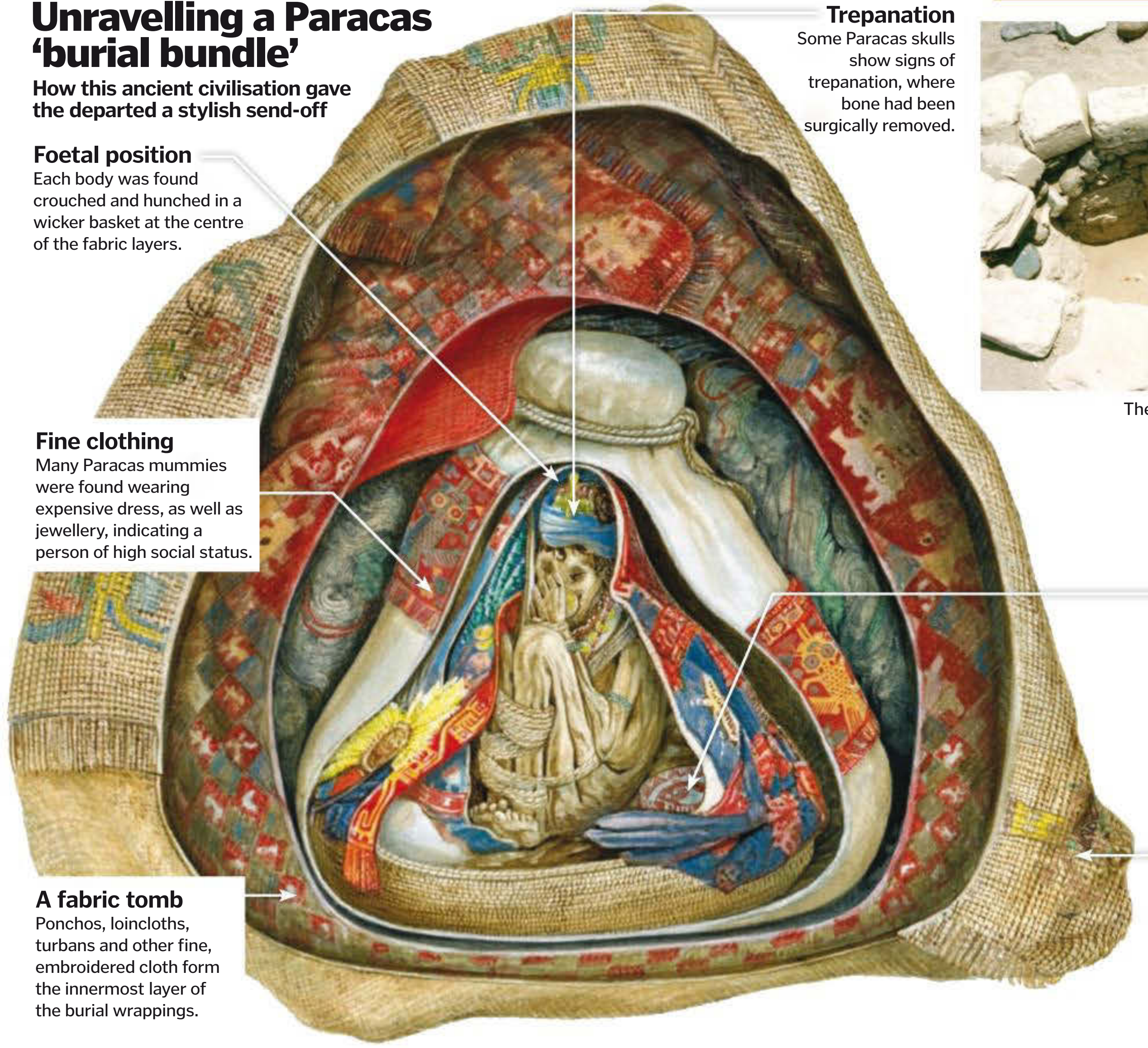
In 1925, Julio Tello found more than 400 graves like this, just south of the city of Pisco in Peru. Each mummified corpse was encased in so many layers of textiles that, from the outside, they appeared like small, conical parcels or bundles. Two Paracas burial sites were identified in Peru, known as the Caverns and the Necropolis. The Caverns site is shaped like a wine glass, with a six-metre shaft leading down to the chamber where the burial bundles are gathered together.

An Ancient Assyrian funeral

During the same period but in ancient Turkey, burial pits were often furnished with turtles and terrapins to accompany the deceased. It's thought the Ancient Assyrians believed these creatures could ward off evil spirits, and act as psychopomps – magical beings to guide the dead person's soul to the underworld. Archaeologists in eastern Turkey recently found evidence of reptilian remains at a burial site dating back to 700-300 BCE, and suspect the unfortunate turtles were even served as funeral snacks first.

Unravelling a Paracas 'burial bundle'

How this ancient civilisation gave the departed a stylish send-off



Foetal position
Each body was found crouched and hunched in a wicker basket at the centre of the fabric layers.

Trepanation
Some Paracas skulls show signs of trepanation, where bone had been surgically removed.

Fine clothing
Many Paracas mummies were found wearing expensive dress, as well as jewellery, indicating a person of high social status.

Personal effects
As well as food and riches, ceramic pots and cups were found within many burials, intricately decorated with depictions of jaguars, birds and snakes.

A fabric tomb
Ponchos, loincloths, turbans and other fine, embroidered cloth form the innermost layer of the burial wrappings.

Outer shell
In some cases, more than 60 layers of cloth were used to complete the 'burial bundle', and ceremonial masks or totems would be attached to the outer layer for prestigious occupants.

The Nazca people of Peru, who lived at the same time as the Paracas, also mummified their dead

© WIKI; Illustration by Art Agency/Sandra Doyle

DID YOU KNOW? *Charles Darwin discovered that earthworms were to blame for the sinking of Stonehenge*

Britain's tribal territories

Before the Roman invasion in 55 BC, Britain was characterised by a large number of ancient tribes, each with its own culture

While the first modern humans populated the area we now call Britain at the end of the Ice Age (6,500 BC), very little is known about the intricacies of their culture and peoples until recorded history begins circa the Roman invasion of 55 BC. Without Roman chroniclers of the time such as Tacitus and Ptolemy, who met the ancient tribes of Britain either in trade or in war, our sketchy picture of these peoples would be even more incomplete. However, centuries of historical records, stories and archaeological finds have given us a snapshot of their lives.

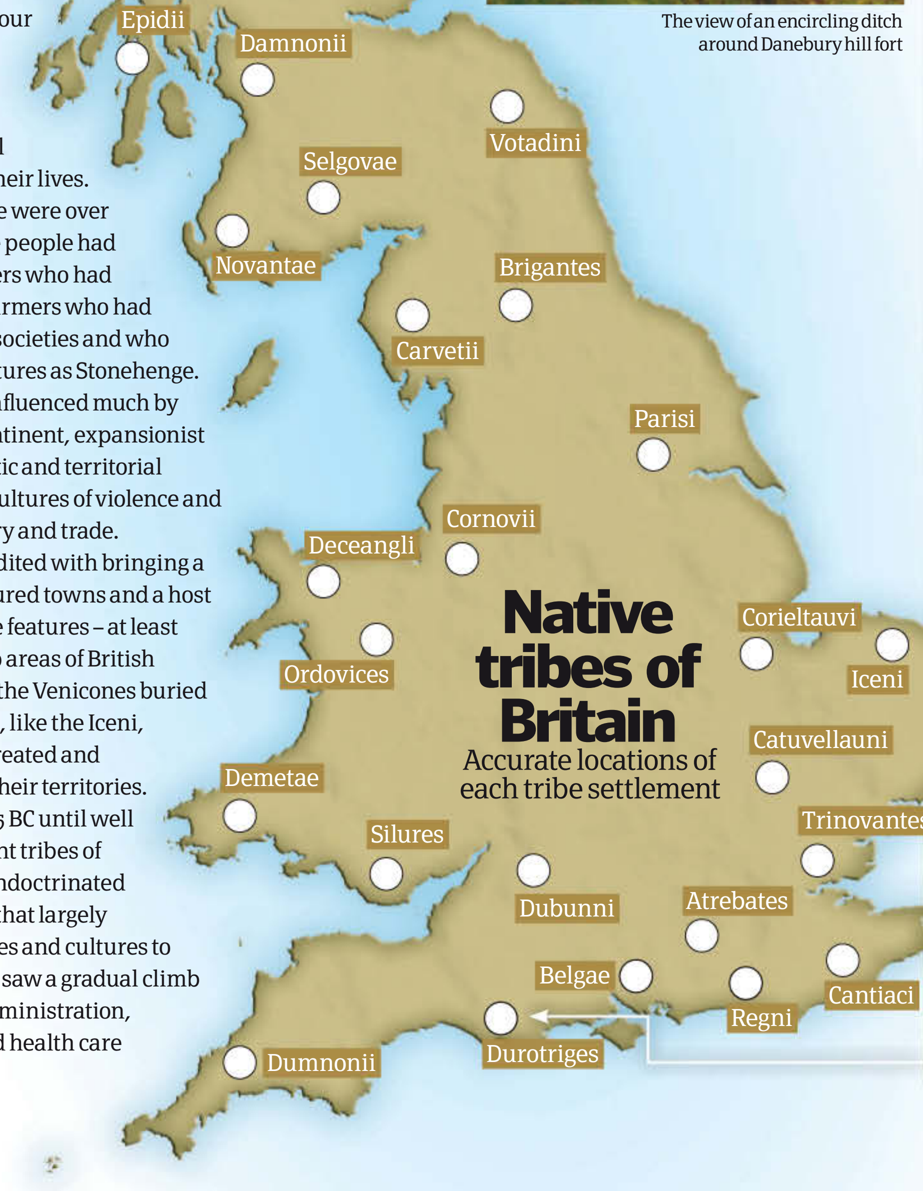
Before the Roman invasion there were over 27 separate tribes in Britain. These people had grown from the early hunter-gathers who had inhabited the area, and later the farmers who had developed agriculturally focused societies and who had built such sophisticated structures as Stonehenge. For the last 600 years BC though, influenced much by the arrival of the Celts from the continent, expansionist tribal kingdoms headed by dynastic and territorial rulers and chieftains arose, with cultures of violence and sophisticated manufacture, artistry and trade.

While the Romans are often credited with bringing a unified currency, as well as structured towns and a host of amenities and technology, these features – at least part – were already integrated into areas of British tribal society. Some tribes such as the Venicones buried their dead in stone casings. Others, like the Iceni, Catuvellauni and Atrebates, had created and distributed currency throughout their territories.

Over 200 years, however, from 55 BC until well into the 2nd Century AD, the ancient tribes of Britain were either conquered or indoctrinated into the Roman empire, a process that largely converted the population's attitudes and cultures to those shared on the continent and saw a gradual climb in society towards standards of administration, architecture, sanitary systems and health care that resonate with today's society.

© Rhys Jones

The view of an encircling ditch around Danebury hill fort



Native tribes of Britain

Accurate locations of each tribe settlement

Head to Head

ANCIENT BRITISH TRIBES

MOST REBELLIOUS

© PHGCOM

1. Iceni

Located: Norfolk

Facts: One of the most rich and powerful tribes in Britain, the Iceni revolted against the Romans after the death of their client-king Prasutagus and were lead until her death by Prasutagus' wife, the renowned Queen Boudicca.

MOST CIVILISED

© John Opie

2. Catuvellauni

Located: South-east

Facts: One of the most pro-Roman tribes, the Catuvellauni quickly adopted Roman lifestyles and, as a result, were made very rich and powerful. One of the most famous British tribal kings, Cunobelinus, originally heralded from the Catuvellauni.

MOST DEFENSIVE

© Nigel Mykura

3. Durotriges

Located: Dorset

Facts: A southern tribe, the Durotriges differed from others by remaining largely in hill forts long after others had abandoned them. They were huge traders and, through numerous harbours, exchanged many goods with the Romans.

Maiden Castle, a great example of an Iron Age, multi-ditch hill fort

© Ray Beer

Ancient Greek theatres

Discover how these massive amphitheatres were built and used

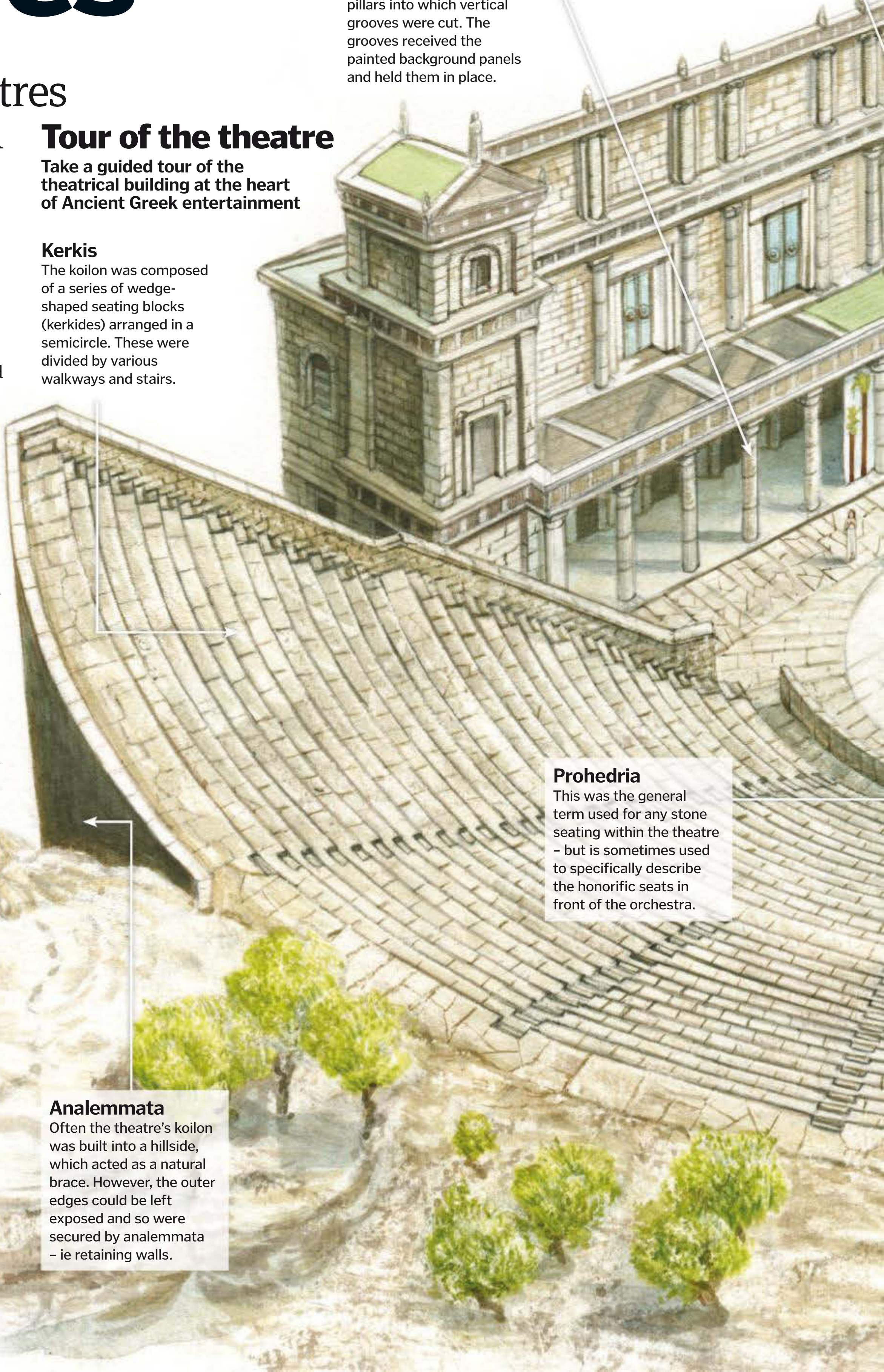
With the invention of tragedies in the late-sixth century BCE, comedies in the fifth century BCE and the satyr play tragicomedies around the first century BCE, the Ancient Greeks had to build a huge number of impressive theatres to do their plays justice. As the centuries went on – and the popularity of the theatre grew and grew – the buildings had to expand and adapt to meet the demand. Indeed, many of these semicircular amphitheatres could seat well over 10,000 people and were used frequently during religious festivals such as the Dionysia, a major celebration centred around the god Dionysus.

While the theatres of the Ancient Greeks began as simple clearings with a smattering of wooden benches for the audience to sit on, before long they had grown into full-blown sanctuary-like facilities. These included large banks of stone seats, a vast orchestra and acting area, a complex backstage network of rooms, entrances and trapdoors, as well as a wide selection of ornate and decorative scenic backdrops. These features, along with the Ancient Greeks' love for festivals, led theatres to take a central role in cementing and spreading Greek culture – something the Romans would later adopt for themselves.

Theatres were made primarily out of stone, often with the amphitheatre's seats placed into the side of a hill for extra support, while traditional construction methods for civic buildings and temples were transferred for the production of colonnades, scenery and entranceways. Interestingly, the greatest technical feat in constructing many of these theatres were the excellent acoustics, with the shape and angle of the seating arrangement and materials (limestone was a popular choice, for instance) serving as acoustic traps. These would filter out low-frequency sounds like spectator chatter and enhance the high frequencies of the performers' voices.

Tour of the theatre

Take a guided tour of the theatrical building at the heart of Ancient Greek entertainment



Kerkis
The koilon was composed of a series of wedge-shaped seating blocks (kerkides) arranged in a semicircle. These were divided by various walkways and stairs.

Thyroma
These structures were stone pillars into which vertical grooves were cut. The grooves received the painted background panels and held them in place.

Episkenion
The upper storey of the skene. Accessed by a ramp or stairwells, it provided an additional acting/singing space.

Prohedria
This was the general term used for any stone seating within the theatre – but is sometimes used to specifically describe the honorific seats in front of the orchestra.

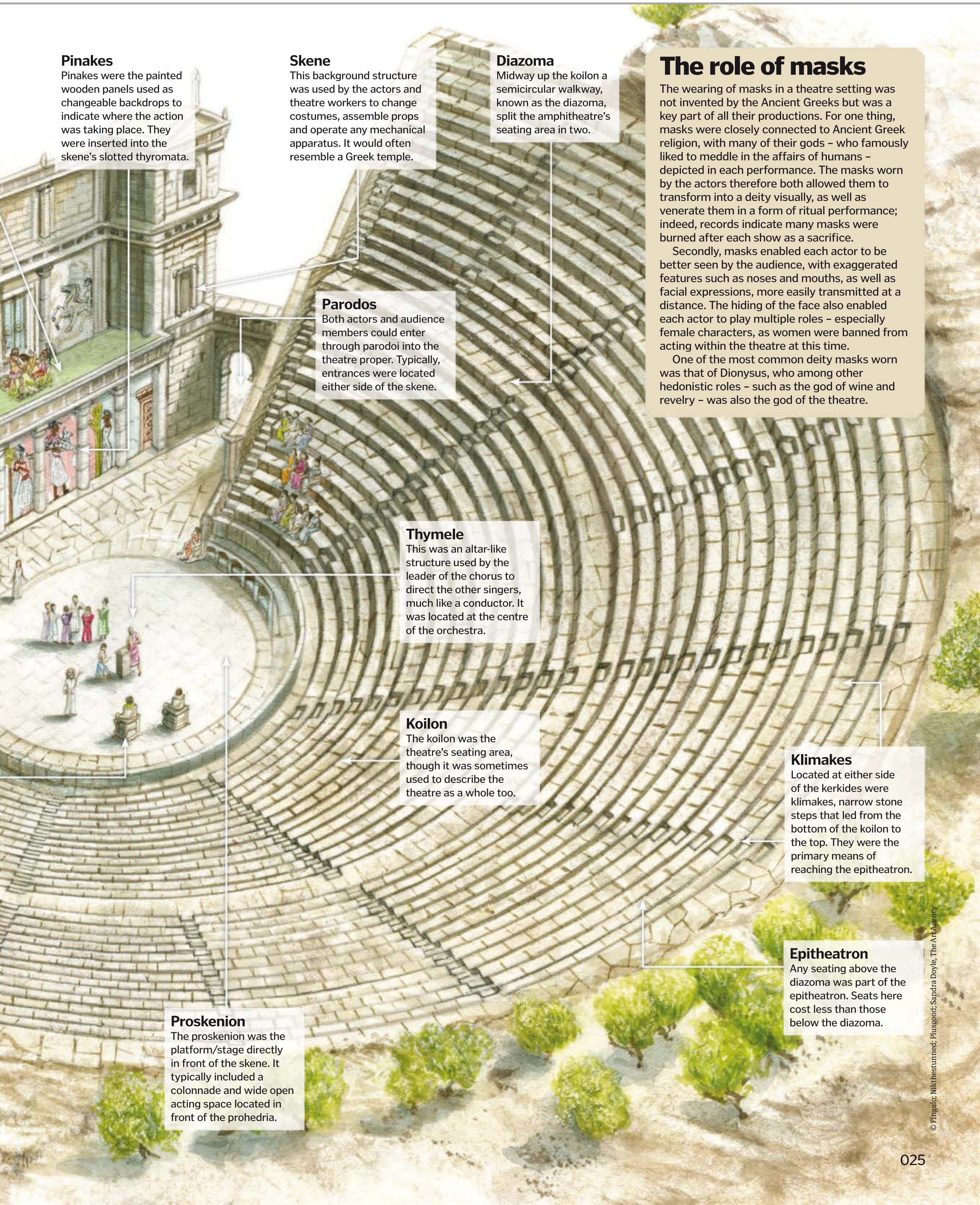
Analemmata
Often the theatre's koilon was built into a hillside, which acted as a natural brace. However, the outer edges could be left exposed and so were secured by analemmata – ie retaining walls.

The role of masks

The wearing of masks in a theatre setting was not invented by the Ancient Greeks but was a key part of all their productions. For one thing, masks were closely connected to Ancient Greek religion, with many of their gods – who famously liked to meddle in the affairs of humans – depicted in each performance. The masks worn by the actors therefore both allowed them to transform into a deity visually, as well as venerate them in a form of ritual performance; indeed, records indicate many masks were burned after each show as a sacrifice.

Secondly, masks enabled each actor to be better seen by the audience, with exaggerated features such as noses and mouths, as well as facial expressions, more easily transmitted at a distance. The hiding of the face also enabled each actor to play multiple roles – especially female characters, as women were banned from acting within the theatre at this time.

One of the most common deity masks worn was that of Dionysus, who among other hedonistic roles – such as the god of wine and revelry – was also the god of the theatre.



Pinakes
Pinakes were the painted wooden panels used as changeable backdrops to indicate where the action was taking place. They were inserted into the skene's slotted thyromata.

Skene
This background structure was used by the actors and theatre workers to change costumes, assemble props and operate any mechanical apparatus. It would often resemble a Greek temple.

Diazoma
Midway up the koilon a semicircular walkway, known as the diazoma, split the amphitheatre's seating area in two.

Parodos
Both actors and audience members could enter through parodoi into the theatre proper. Typically, entrances were located either side of the skene.

Thymele
This was an altar-like structure used by the leader of the chorus to direct the other singers, much like a conductor. It was located at the centre of the orchestra.

Koilon
The koilon was the theatre's seating area, though it was sometimes used to describe the theatre as a whole too.

Klimakes
Located at either side of the kerkides were klimakes, narrow stone steps that led from the bottom of the koilon to the top. They were the primary means of reaching the epitheatron.

Epitheatron
Any seating above the diazoma was part of the epitheatron. Seats here cost less than those below the diazoma.

Proskenion
The proskenion was the platform/stage directly in front of the skene. It typically included a colonnade and wide open acting space located in front of the prohedria.

© Fingalo; Nikthestunned; Plusgood; Sandra Doyle, The Art Agency

Greek tomb construction

Learn about the unique structures in which the elite of these Ancient Greek people were buried

There were two main types of Mycenaean tomb: chamber tombs and tholos tombs. The former predates the latter and consisted of a rhomboidal chamber cut into rock/earth and finished with a square stone pyramid on the top. No examples of these tombs have been found in modern times, however they are detailed in ledgers of the ancient Babylonian city of Uruk.

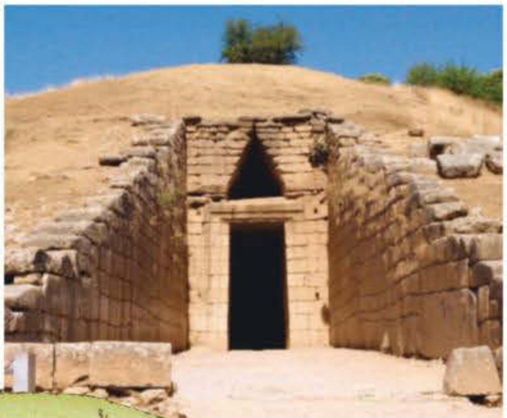
The latter, which became the more common tomb after 1500 BCE, is of a grander design. Tholos tombs, which resemble the shape of a beehive, were conical, false-domed chambers built out of mud bricks and stone. The bricks were commonly laid in a circle on top of one another up to a tapered centre point. After that the entire dome would be covered by an earthen mound (tumulus).

These beehive tombs were accessed via a long approach corridor, or passage, that was known as a dromos, which culminated in a large entranceway, called a stomion. The stomion consisted of a large rectangular brick opening flanked by two stone columns and topped with a single giant stone mantle. Above the mantle a triangular hole was often filled with a decorative relief sculpture.

Inside, off the main conical chamber, lay an antechamber, which was typically rectangular. This could be used either for burials – other family members – or more likely grave goods, such as jewellery and weapons. There's evidence that both the antechamber and main stomion were installed with wooden doors, the latter set slightly back from the main façade.

Who were the Mycenaeans?

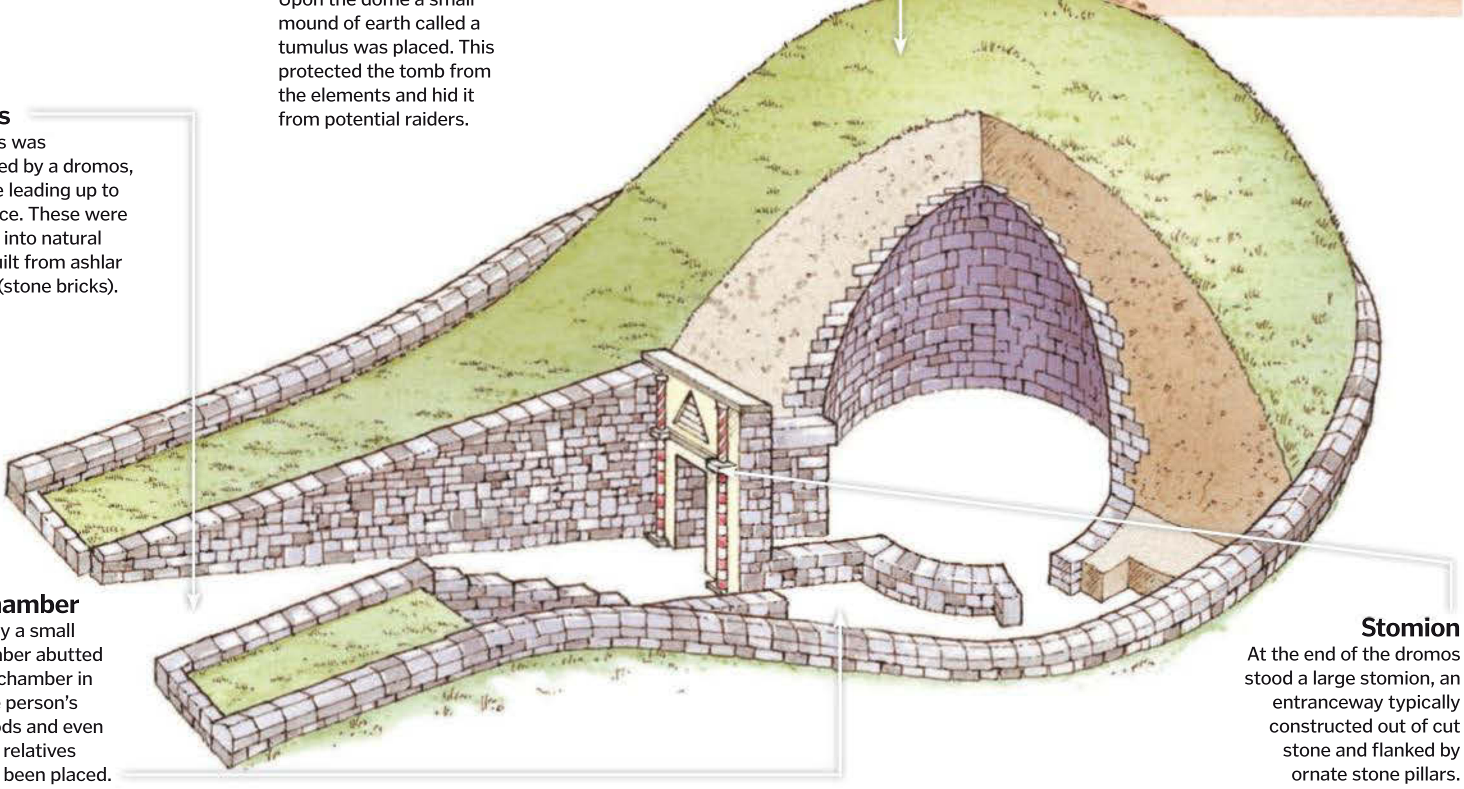
The Mycenaean civilisation occupied much of modern-day central Greece and flourished between 1600 and 1100 BCE. Unlike the earlier Minoan settlers of the area whose society expanded and prospered through trade, the Mycenaeans advanced theirs through military conquest. One of the most notable examples of the Mycenaean expansion through war is recorded in Homer's *The Iliad*, where the king of Mycenae, Agamemnon, and the united forces of Greece took the city of Ilium (Troy) in north-west Anatolia (Turkey). Another advance saw the Mycenaeans capture the island of Crete.



© DK Images; Thinkstock

A tholos tomb unearthed

Discover the major elements that made up the final resting places of the Mycenaean aristocracy



Tumulus
Upon the dome a small mound of earth called a tumulus was placed. This protected the tomb from the elements and hid it from potential raiders.

Dromos
The tholos was approached by a dromos, an avenue leading up to its entrance. These were either cut into natural rock or built from ashlar masonry (stone bricks).

Antechamber
Commonly a small antechamber abutted the main chamber in which the person's grave goods and even deceased relatives may have been placed.

Stomion
At the end of the dromos stood a large stomion, an entranceway typically constructed out of cut stone and flanked by ornate stone pillars.

DID YOU KNOW? *Panoply is the term used to describe a complete set of hoplite armour and weaponry*

Greek warriors

The hoplites of Ancient Greece were some of the most feared fighters in the world. Find out why they were so hard to defeat

Both in Homeric and post-Homeric Greece, hoplite warriors were considered the most deadly and efficient soldiers on the battlefield. Armed with a variety of highly refined weapons – such as spears, swords and daggers, protected by toughened bronze armour and extremely adept at executing cunning tactics and formations, these famous Ancient Greek warriors tore through many an enemy army with considerable ease.

Arguably, hoplites really came into their own around the sixth century BCE. Prior to this point Greek warriors – who were self-armed and trained civilians – fought for personal, familial or national honour singularly. They obviously grouped under city-state banners to wage wars if needed, but when the battle started, the onus was very much on man-to-man single combat; indeed, many battles of this period began with army commanders/heroes facing off against each other solo.

After the introduction of advanced military formations such as the phalanx – see 'Wall of death' (below) for more – circa 700 BCE, soldiers began to fight battles as cohesive military units.

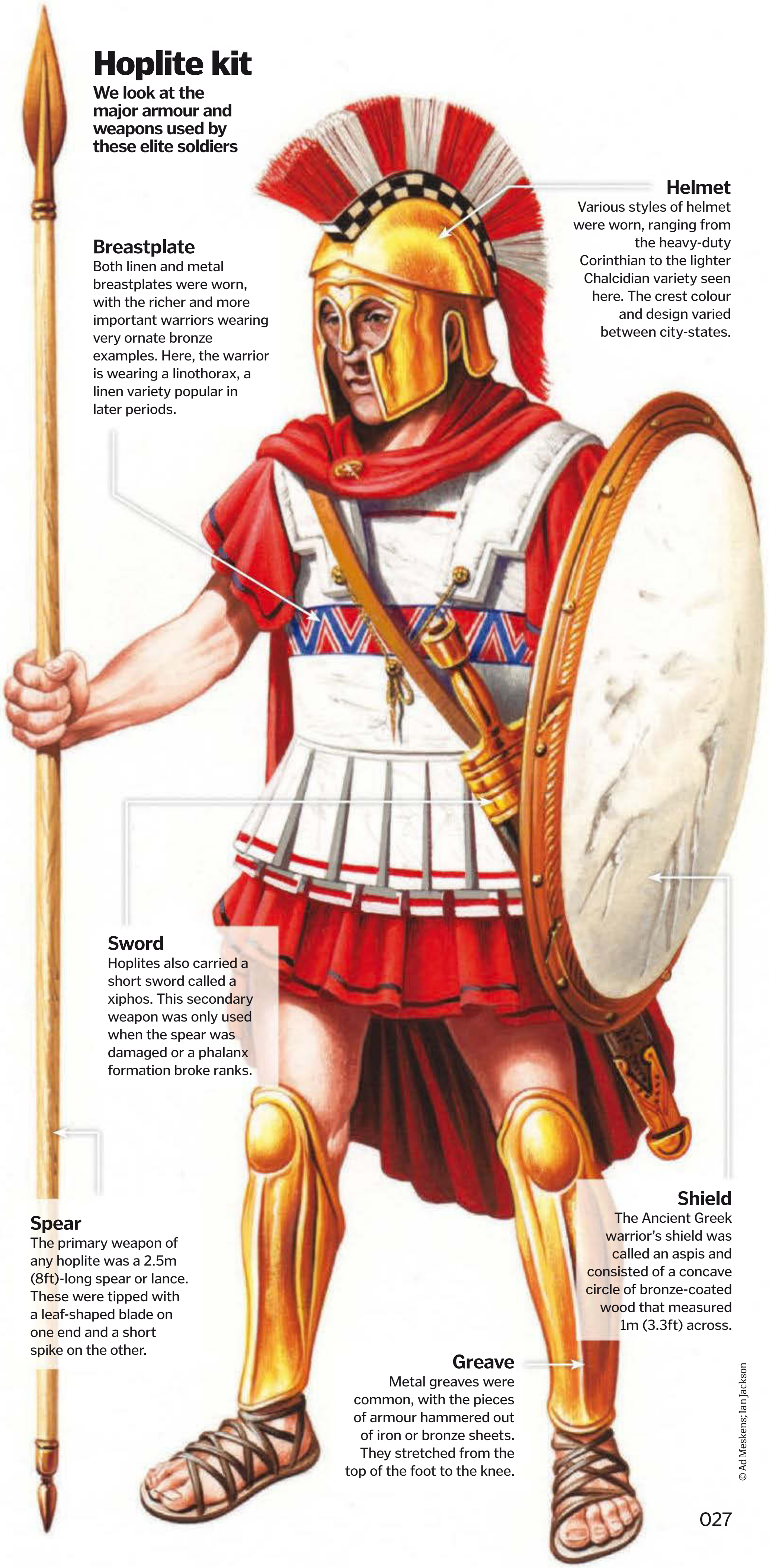
This increased their battle prowess further and, by the time of the massive Persian invasion of 480 BCE, enabled them to win a series of decisive battles against forces that, going on the numbers, they should have lost.

Wall of death

Aside from their good training, weapons and armour, a key reason hoplite warriors were so feared was their use of formations. Chief among these was the phalanx, a rectangular mass formation composed of heavy infantry that, by engaging the enemy as one, allowed the warriors to effectively crush any foe in their path. The phalanx was created by arranging hoplites in lines typically eight to ten men deep, with the front rank of soldiers interlocking their shields together. The long rectangular body of soldiers would then slowly advance, spears outstretched, skewering any enemies ahead.

Hoplite kit

We look at the major armour and weapons used by these elite soldiers



Helmet
Various styles of helmet were worn, ranging from the heavy-duty Corinthian to the lighter Chalcidian variety seen here. The crest colour and design varied between city-states.

Breastplate
Both linen and metal breastplates were worn, with the richer and more important warriors wearing very ornate bronze examples. Here, the warrior is wearing a linothorax, a linen variety popular in later periods.

Sword
Hoplites also carried a short sword called a xiphos. This secondary weapon was only used when the spear was damaged or a phalanx formation broke ranks.

Spear
The primary weapon of any hoplite was a 2.5m (8ft)-long spear or lance. These were tipped with a leaf-shaped blade on one end and a short spike on the other.

Shield
The Ancient Greek warrior's shield was called an aspis and consisted of a concave circle of bronze-coated wood that measured 1m (3.3ft) across.

Greave
Metal greaves were common, with the pieces of armour hammered out of iron or bronze sheets. They stretched from the top of the foot to the knee.

© Ad Meskens; Ian Jackson

Aztec warriors

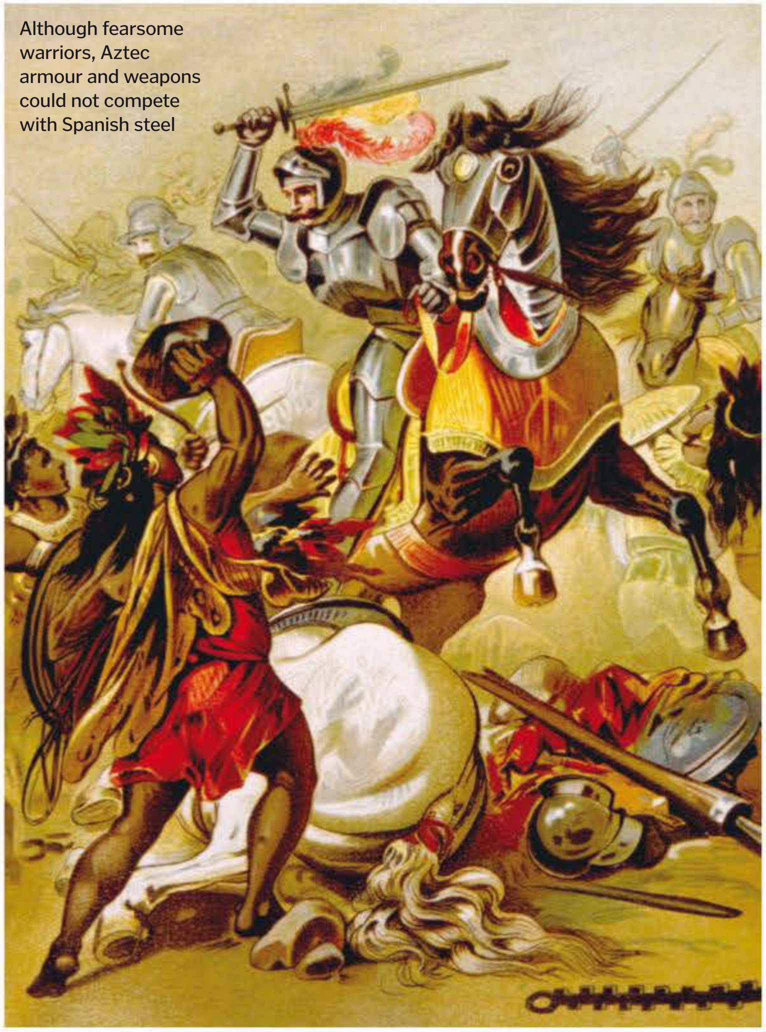
Ready yourself for battle as you learn about the martial side of this Central American civilisation

The Aztecs were a fierce and powerful group of warriors, defined by their religious fervour and class system.

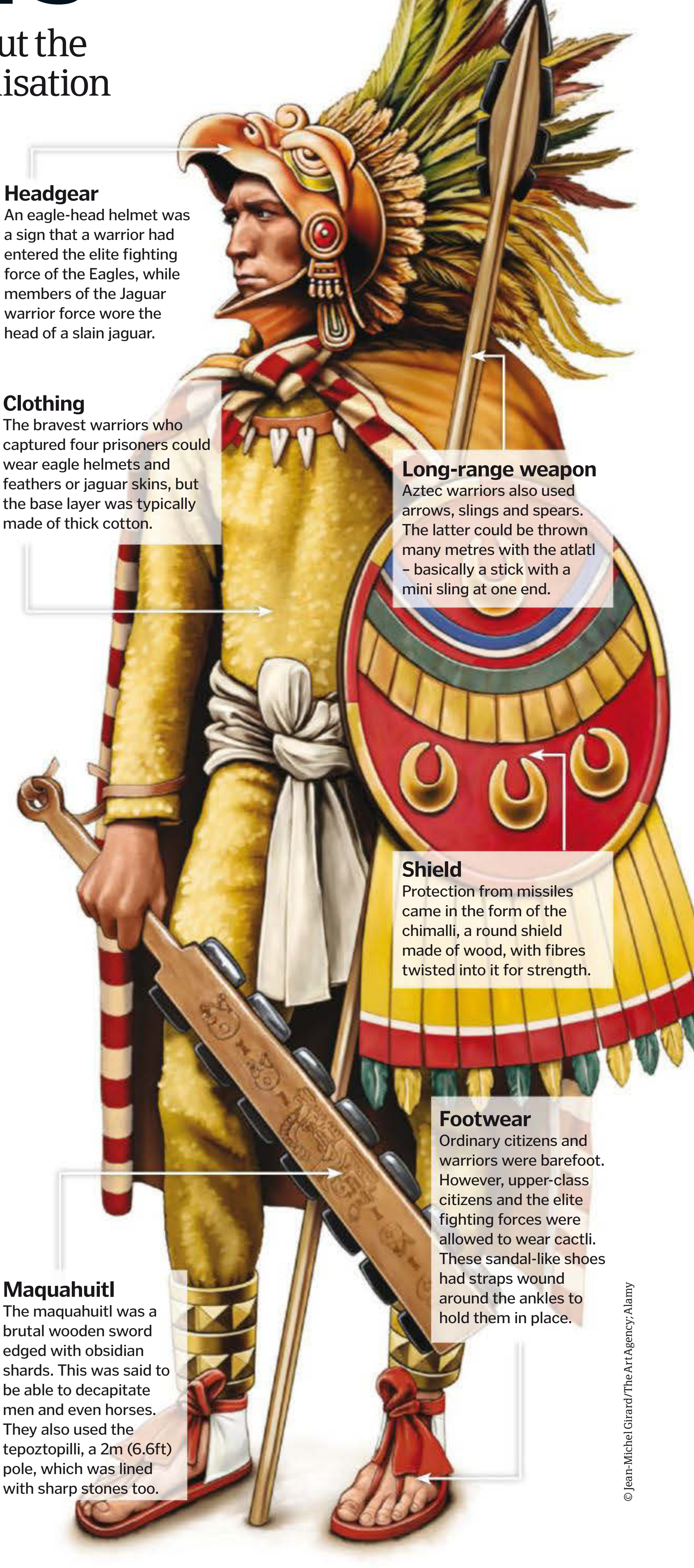
New warriors had to work their way up from the bottom by capturing prisoners. This was an important part of a young warrior's introduction into the martial society, as the Aztecs would sacrifice prisoners to the god Huitzilopochtli. Once a warrior had captured a prisoner, he would attain the rank of a warrior.

Most Aztecs wore padded cotton armour called ichcahuipilli, which remained cool in the intense heat of Mexico but was also tough enough to deflect most arrows and darts. However, the elite fighting forces – called the 'Eagles' and 'Jaguars' – dressed as their namesakes. Eagle warriors donned feathers and an eagle-head helmet (see annotated warrior), while Jaguar fighters were wrapped in the skin of the South American big cat. The higher up the social rank you rose, the more elaborate the costume became.

Their main weapon was the maquahuitl, a wooden sword with vicious shards of obsidian embedded down the sides. This deadly tool was capable of beheading a human. The Aztecs were also proficient users of arrows, slings and the atlatl, a throwing device that allowed them to hurl spears harder and faster than possible with the arm alone.



Although fearsome warriors, Aztec armour and weapons could not compete with Spanish steel



Headgear
An eagle-head helmet was a sign that a warrior had entered the elite fighting force of the Eagles, while members of the Jaguar warrior force wore the head of a slain jaguar.

Clothing
The bravest warriors who captured four prisoners could wear eagle helmets and feathers or jaguar skins, but the base layer was typically made of thick cotton.

Long-range weapon
Aztec warriors also used arrows, slings and spears. The latter could be thrown many metres with the atlatl – basically a stick with a mini sling at one end.

Shield
Protection from missiles came in the form of the chimalli, a round shield made of wood, with fibres twisted into it for strength.

Footwear
Ordinary citizens and warriors were barefoot. However, upper-class citizens and the elite fighting forces were allowed to wear cactli. These sandal-like shoes had straps wound around the ankles to hold them in place.

Maquahuitl
The maquahuitl was a brutal wooden sword edged with obsidian shards. This was said to be able to decapitate men and even horses. They also used the tepoztopilli, a 2m (6.6ft) pole, which was lined with sharp stones too.

© Jean-Michel Girard/The Art Agency; Alamy

DID YOU KNOW? *Despite the stereotype, only a select few Native American tribes practised scalping*

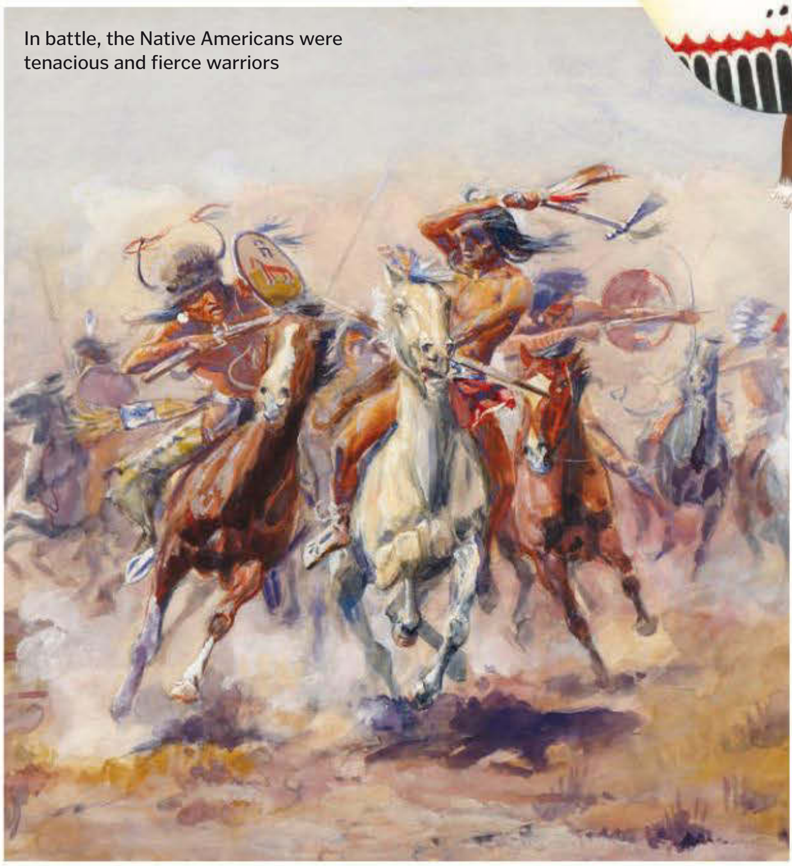
Native American warrior

Check out the key kit as carried by a fighter from the Dakota Sioux tribe

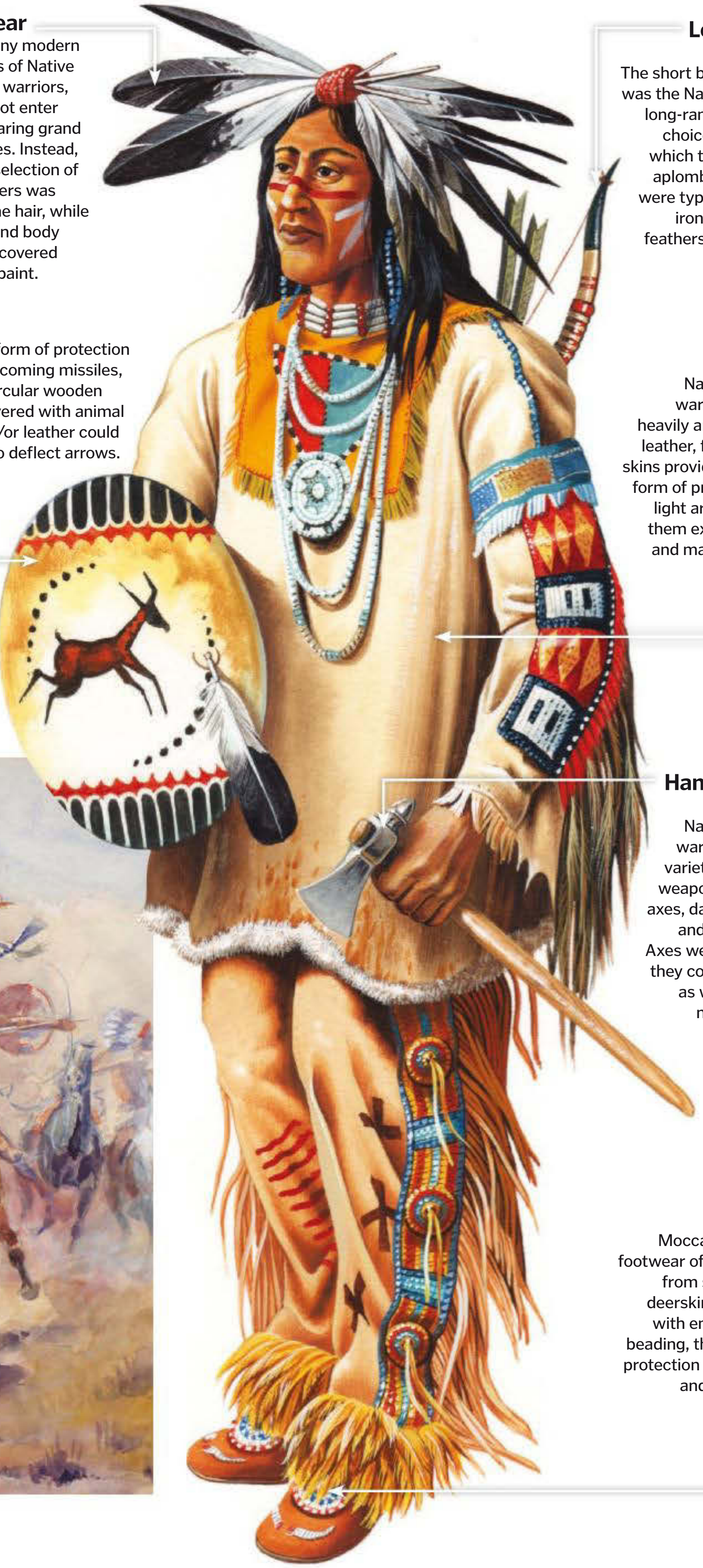
Despite being lightly armoured, Native American warriors were fierce combatants, well-trained in both hand-to-hand and ranged combat. Armed with a selection of bows, spears, swords, daggers, axes and even – in the later decades of the 19th century – guns, Westerners coming to claim the Indians' land were in for a shock.

Indeed, despite their superior firepower, armour and resources, British and American armies often found themselves outmanoeuvred and outfought, with the Native American warriors' expert horsemanship skills allowing them to strike quickly and with deadly precision, taking out large swathes of the invading forces before retreating to the safety granted by their knowledge of the territory.

Both the Native Americans' excellent combat skills and innovative use of terrain in battle tactics meant that it took the British and then Americans over 150 years to evict all of the Native American tribes in North America onto the reservations that many of their descendants inhabit today. And they did so at great cost, with thousands of soldiers being cut down by their fierce and agile opposition right up until the turn of the 20th century.



In battle, the Native Americans were tenacious and fierce warriors



Headgear
Unlike many modern depictions of Native American warriors, they did not enter battle wearing grand headpieces. Instead, a simple selection of bird feathers was worn in the hair, while the face and body would be covered with war-paint.

Shield
The only form of protection against incoming missiles, a small circular wooden shield covered with animal skins and/or leather could be used to deflect arrows.

Long-range weapon
The short bow and arrow was the Native American long-range weapon of choice – something which they used with aplomb. Arrowheads were typically made of iron, while the tail feathers of birds were used as fins.

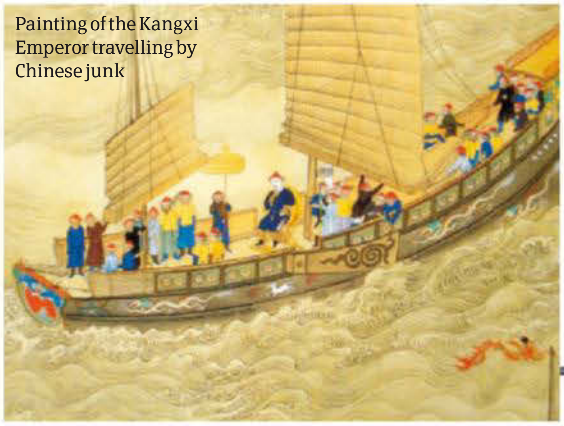
Clothing
Native American warriors were not heavily armoured, with leather, fur and animal skins providing their only form of protection. This light armour granted them excellent agility and manoeuvrability.

Hand-to-hand weapon
Native American warriors carried a variety of handheld weaponry, including axes, daggers, spears and even swords. Axes were popular, as they could be thrown as well as used in melee combat.

Footwear
Moccasins were the footwear of choice. Made from soft leather or deerskin and adorned with embroidery and beading, they offered no protection but were light and comfortable.

© Ian Jackson

© Remi Jouan



Painting of the Kangxi Emperor travelling by Chinese junk

Chinese junks

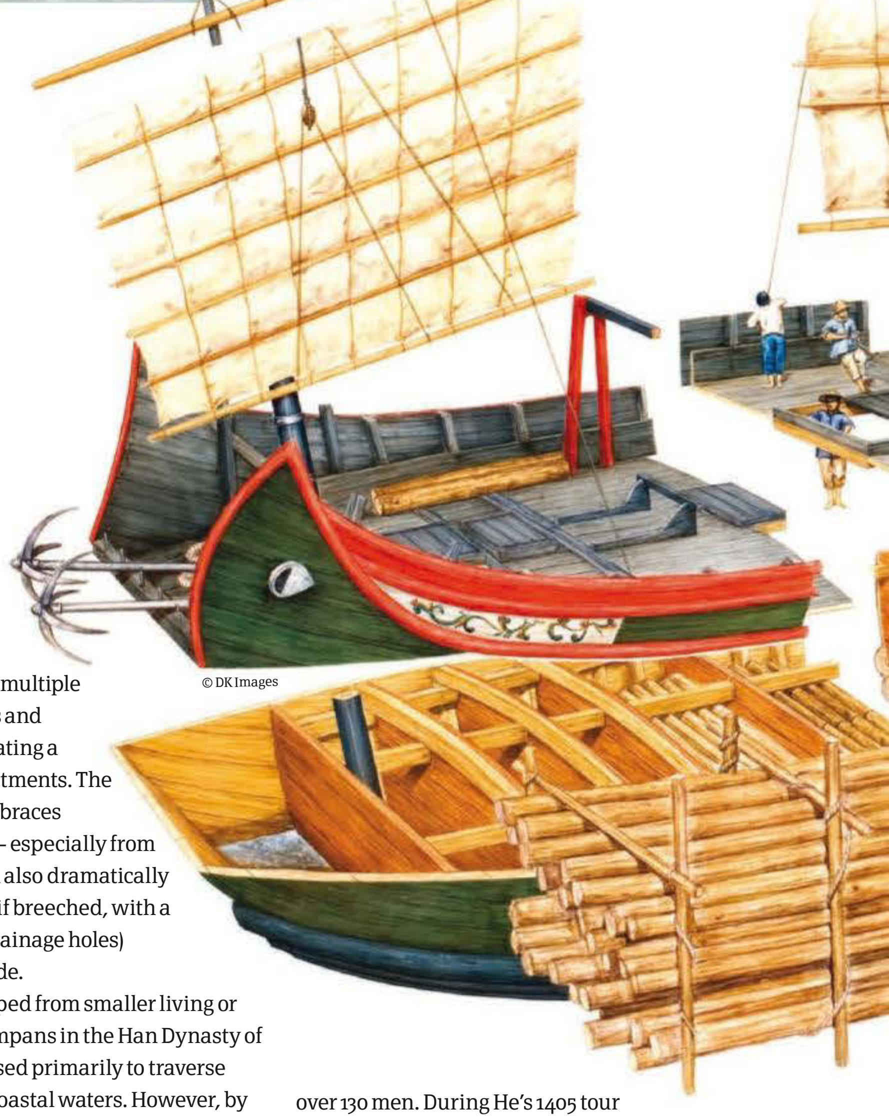
Highly versatile, the Chinese junk has been used since the second Century AD, granting dynamic sailing controls and high speed

Chinese junks – variously sized trading and transportation ships used in Asia from the second Century AD to the modern day – work by partnering a sturdy keelless hull with a versatile and mobile sail-plan, in order to generate a fast and highly stable sailing platform.

The sail-plan of a junk differs from that of traditional square-rigged ships, with the junk's various sails capable of being moved inwards towards the ship's lengthy central axis, allowing it to be easily modified in order to sail into the wind. The sails themselves also differ from the traditional variety, with long horizontal struts called battens providing a rigid shape – akin to that of Venetian blinds – and greater tear-resistance in high wind. Further increasing the power and speed of a junk is its tendency to spread its sails over multiple masts, with five or more common on larger vessels.

Junk hulls were traditionally constructed from softwoods such as cedar and sported a horseshoe-shaped stern, elevated poop deck and flat base with no keel. Due to this, junk hulls are fitted with an overly large keel and series of lee and centreboards (lifting foils) to remain stable. Hulls were also strengthened greatly by multiple partitioning lengthways and sideways internally, creating a series of interior compartments. The addition of these matrix braces increased hull integrity – especially from sideways pressure – and also dramatically reduced flooding speed if breeched, with a series of limber holes (drainage holes) transferring water outside.

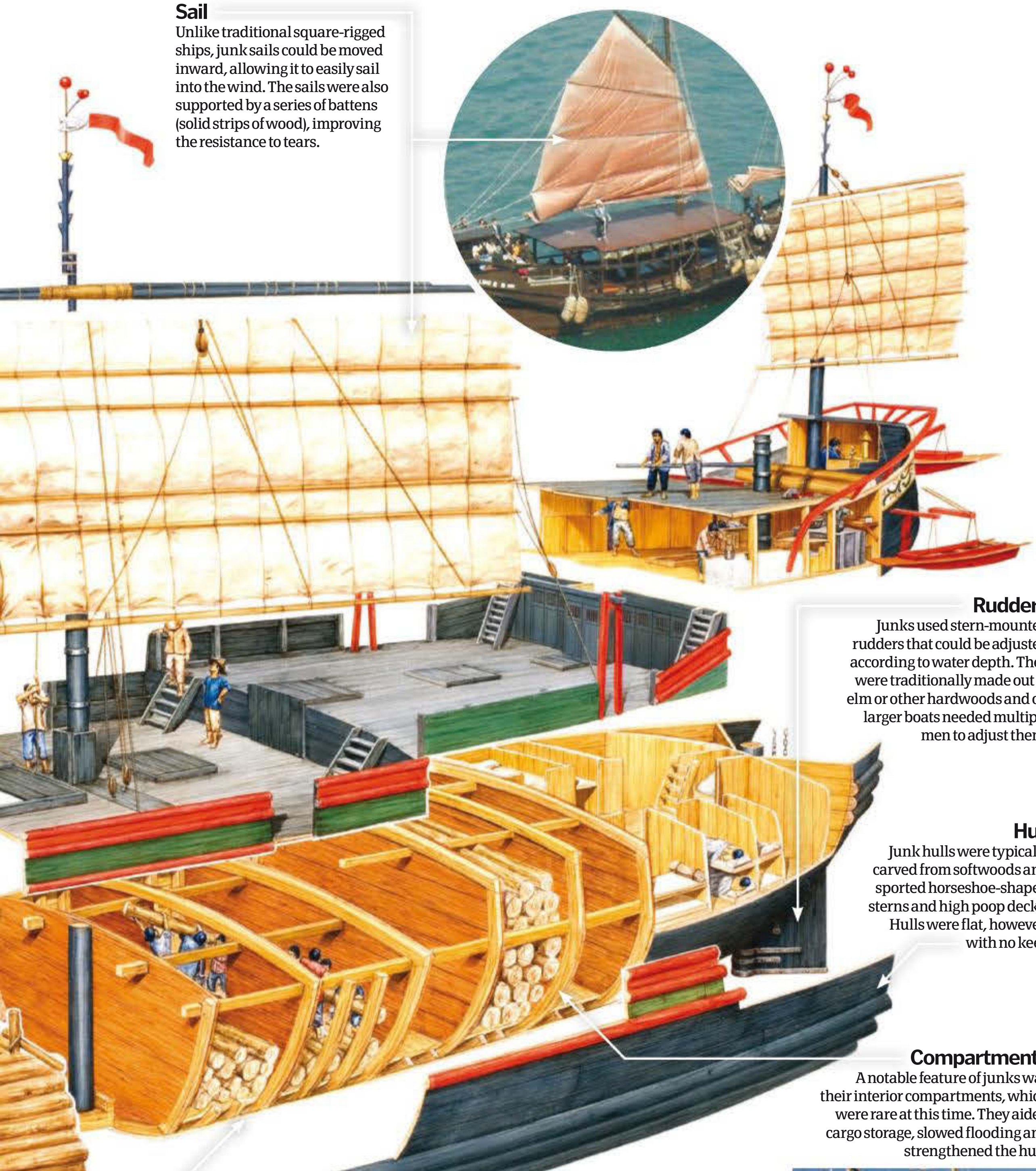
Chinese junks developed from smaller living or fishing boats such as sampans in the Han Dynasty of 206 BCE-220 AD, being used primarily to traverse inland waterways and coastal waters. However, by the 15th Century AD their size and role had evolved massively into trans-continent trading and military vessels, carrying hundreds of men and tons of products. Indeed, according to Chinese historical documentation, during the missions of renowned explorer and mariner Zheng He, junks had been transformed into 420-feet long, 180-feet wide treasure ships, boasting nine masts and crewed by over 130 men. During He's 1405 tour of the Indian Ocean, the explorer commanded over 300 junks and 30,000 men.



© DK Images

Today, the role of junks has diminished from its military and trading height due to the rise of modern technology and transportation methods. However, they are still commonly used by civilians to fish, commute, trade and travel, as well as by tourists who board them on sightseeing tours.

DID YOU KNOW? *Chinese junks developed in the Han Dynasty of 206 BCE-220 AD*



Sail
Unlike traditional square-rigged ships, junk sails could be moved inward, allowing it to easily sail into the wind. The sails were also supported by a series of battens (solid strips of wood), improving the resistance to tears.

Rudders
Junks used stern-mounted rudders that could be adjusted according to water depth. They were traditionally made out of elm or other hardwoods and on larger boats needed multiple men to adjust them.

Hull
Junk hulls were typically carved from softwoods and sported horseshoe-shaped sterns and high poop decks. Hulls were flat, however, with no keel.

Compartments
A notable feature of junks was their interior compartments, which were rare at this time. They aided cargo storage, slowed flooding and strengthened the hull.

Lee/centreboards (not shown)
Leeboards and centreboards were used to stabilise the junk and improve its capability to sail upwind.

The design spread through Asia, as seen in this Vietnamese variant

© Thomas Schoch

Traditionally junks were made from softwoods

2 x © Paul A. Hernandez

Head to Head

TRADING VESSEL EVOLUTION

LARGE

© Bernard Gagnon

Junk
Along with sampans, junk ships developed from smaller fishing vessels. Their flat-bottomed design and Venetian blind-type sails allowed them to remain stable in rough conditions and sail against the wind with great ease. They originated in Asia but spread throughout the Middle East and Africa through trade in the early centuries AD.

LARGER

© Tomasz Sienicki

Galleon
Evolving from the carrack – the predominant sailing vessel of the 14th and 15th Century – the galleon was a multi-decked ship used for warfare and trade. Galleons developed in Portugal and Spain in the 16th Century and were used throughout Europe, Africa and the Caribbean to transport goods along trade routes.

LARGEST

© Huhu Uet

Freighter
The predominant method used today to trade by sea over long distances, freighters can carry hundreds of tons' worth of metal containers filled with goods. These container ships were developed in the middle of the 20th Century and now account for 90 per cent of worldwide trade in non-bulk goods.

The Ancient Celts

How the Iron Age revolutionised this pre-Roman civilisation

The discovery of how to extract iron from its ore changed the world. As the Iron Age was born, new tools could be made for warfare, agriculture, hunting and fishing. Among the main beneficiaries of this new age were the Celts. The Iron Age in Europe lasted from 800 BCE until 43 CE and signalled a significant development of society.

Ploughs, scythes and sickles were fashioned to tend to and gather crops. Rotary querns were introduced to turn grain into flour and hunting tools became sharper and tougher. With iron, an array of swords, helmets and armour could also be fashioned. Clothing accessories developed too, with the creation of iron brooches and torcs.

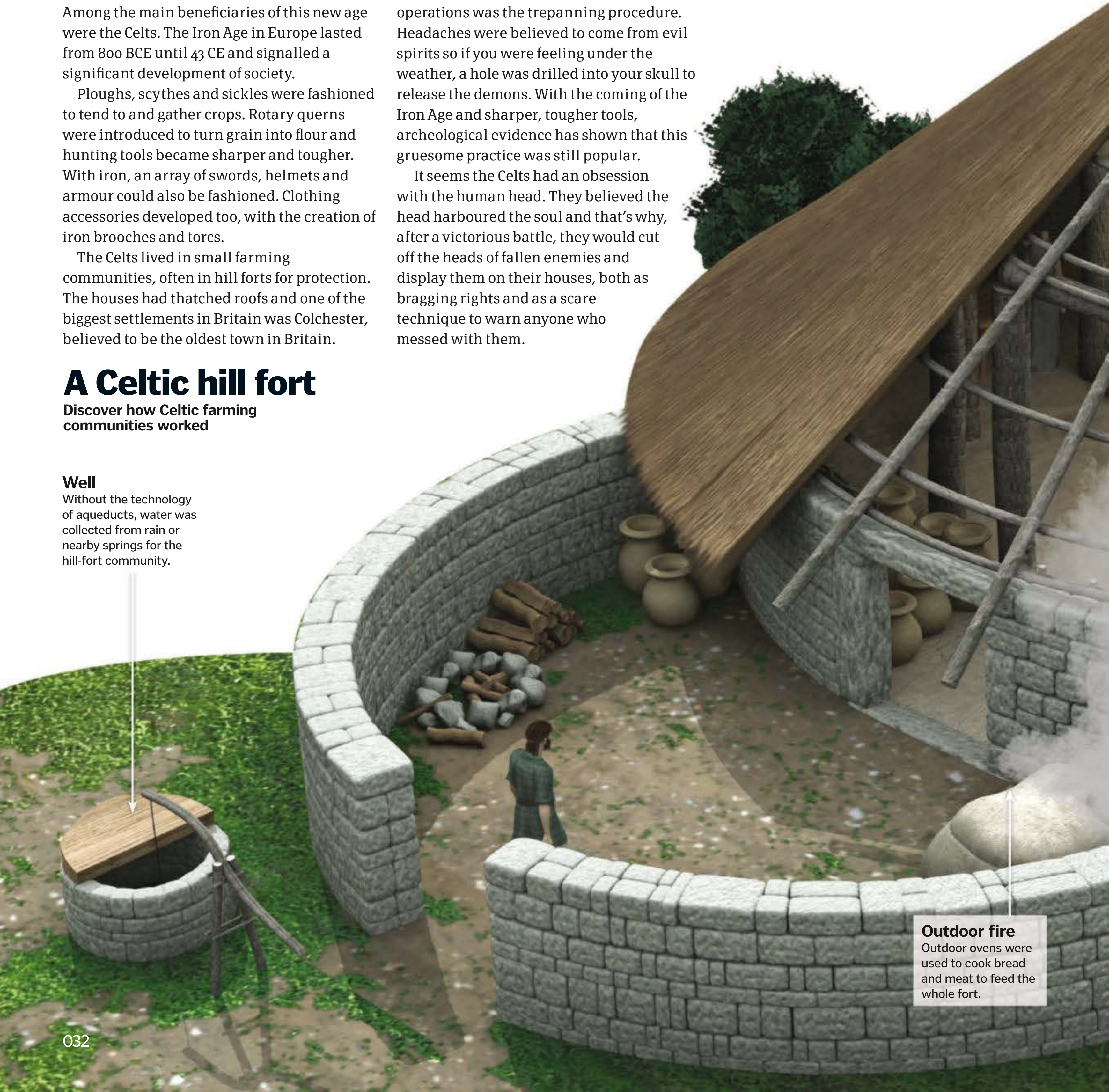
The Celts lived in small farming communities, often in hill forts for protection. The houses had thatched roofs and one of the biggest settlements in Britain was Colchester, believed to be the oldest town in Britain.

If there was any negative aspect to living in the Iron Age it would definitely be their medicine. Still very primitive and led primarily by druids, one of the only surgical operations was the trepanning procedure. Headaches were believed to come from evil spirits so if you were feeling under the weather, a hole was drilled into your skull to release the demons. With the coming of the Iron Age and sharper, tougher tools, archeological evidence has shown that this gruesome practice was still popular.

It seems the Celts had an obsession with the human head. They believed the head harboured the soul and that's why, after a victorious battle, they would cut off the heads of fallen enemies and display them on their houses, both as bragging rights and as a scare technique to warn anyone who messed with them.

A Celtic hill fort

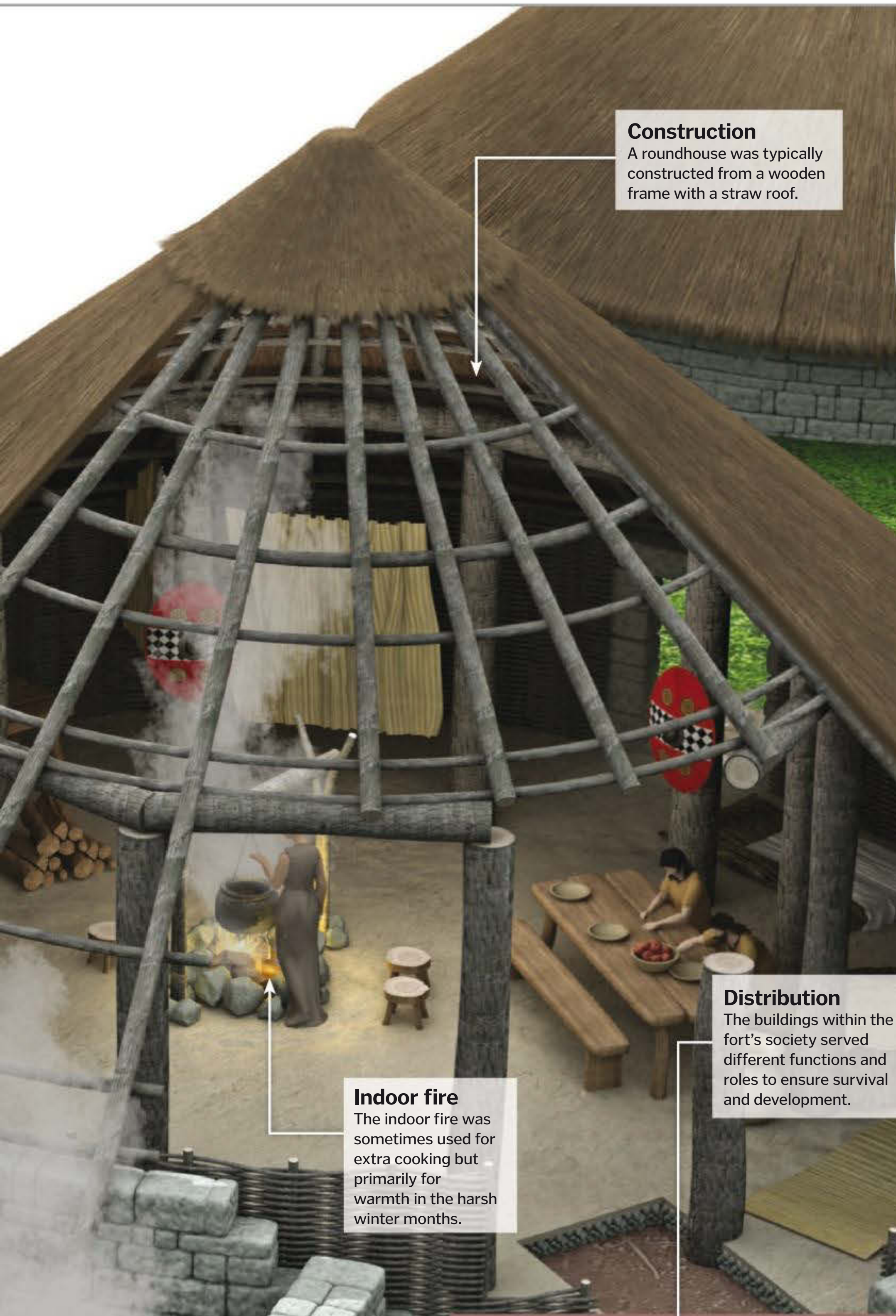
Discover how Celtic farming communities worked



Well
Without the technology of aqueducts, water was collected from rain or nearby springs for the hill-fort community.

Outdoor fire
Outdoor ovens were used to cook bread and meat to feed the whole fort.

DID YOU KNOW? *Female Celts had just as many rights as men. They would fight, own land and achieve status*



Construction
A roundhouse was typically constructed from a wooden frame with a straw roof.

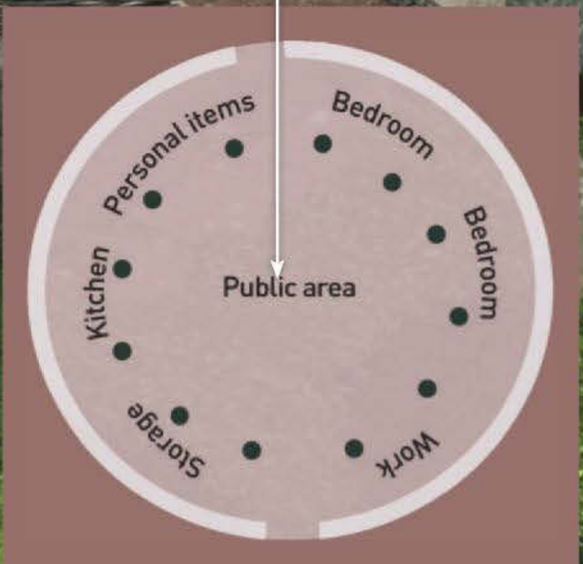
Indoor fire
The indoor fire was sometimes used for extra cooking but primarily for warmth in the harsh winter months.

Hill fort location
Often surrounded by a wooden or stone wall, both natural and man-made defences made the fort tricky for enemies to breach.

A reconstructed roundhouse like the ones Celts lived in

Celtic cities
Celts lived in small communities led by a chieftain and a band of warriors. There were few alliances among the different tribes and no sort of centralised state or government.

Distribution
The buildings within the fort's society served different functions and roles to ensure survival and development.



Who were the Celts?

A term used for many different tribes, the Celts varied from region to region. For instance, the Gauls were based in what is now France and the Celtiberians were located in modern day Spain and Portugal. As their European influence began to come under threat from the Romans and Saxons, many migrated to Britain around 500 BCE. Despite invasions from the Romans, Angles, Saxons, Jutes and Vikings, the Celts still remained established inhabitants in many areas of Britain by the 8th century. However, their lands were now pushed back to Wales and Scotland rather than England, which was primarily Anglo-Saxon territory. Their influence can still be seen today with the uncovering of the Tal-y-Llyn hoard of Iron Age metal tools and weapons and substantial evidence of Celtic hill forts in Maiden Castle and Old Oswestry.

The remains of the Celtic hill fort at Maiden Castle

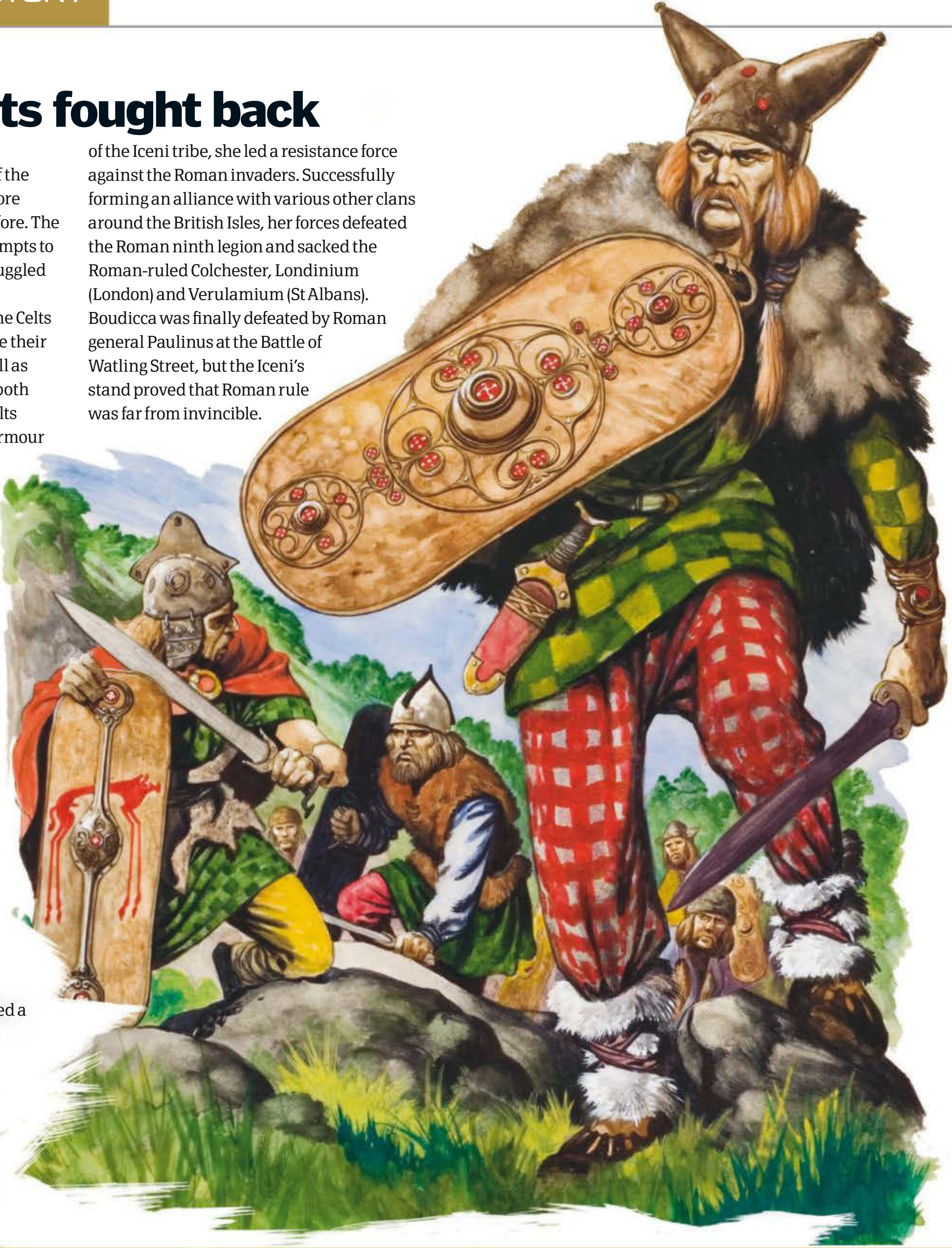
How the Celts fought back

The Celts had a reputation for being fearsome warriors, but the advent of the Iron Age made Celtic Britain even more resistant to overseas attack than before. The mighty Roman army took three attempts to conquer Britain and continually struggled to rule over large parts of the island, especially in Scotland and Wales. The Celts had access to the technology to make their own swords, spears and axes, as well as shields for protection. According to both Greek and Roman historians, the Celts would often go into battle without armour or even completely naked, covered only in war paint. Although there is some evidence to suggest that they used helmets and body armour, these were apparently rare, possibly only used by chieftains and high-ranking warriors.

The Celtic military was primarily based around infantry, but they also used chariots and – occasionally – cavalry during battles. Their tactics weren't as advanced as the Roman testudo, for instance, but they still had some bold strategies up their sleeve.

The most famous is perhaps the Furor Celtica. Translated to ‘Celtic Fury’, it was a mass charge on the front of an enemy line that was used to disrupt and split enemy ranks. Celts on the continent were known to be more defensive and used a tight phalanx set-up, much like the original Greek formation.

The Celtic tribes had many iconic chieftains such as Vercingetorix, Caratacus and Cassivellaunus, but the most famous, without a doubt, was Boudicca (or Boadicea). The fierce and influential warrior queen of the Iceni tribe, she led a resistance force against the Roman invaders. Successfully forming an alliance with various other clans around the British Isles, her forces defeated the Roman ninth legion and sacked the Roman-ruled Colchester, Londinium (London) and Verulamium (St Albans). Boudicca was finally defeated by Roman general Paulinus at the Battle of Watling Street, but the Iceni's stand proved that Roman rule was far from invincible.



What tools and weapons did the Celts use?

Sickles & scythes
Used to cut crops and chop wood, iron scythes and sickles made farming and building simpler and quicker.

Ploughs
The ‘ard’ broke up fertile soil for crops so large communities could be fed, a big reason for the Iron Age population increase.

Spears
The advent of iron smelting brought tougher and sharper spears. These helped in hunting large game and were also used in warfare.

Helmets
The Celts donned two types of helmet: the Montefortino and the Coolus. The latter was the legionnaires' helmet of choice.

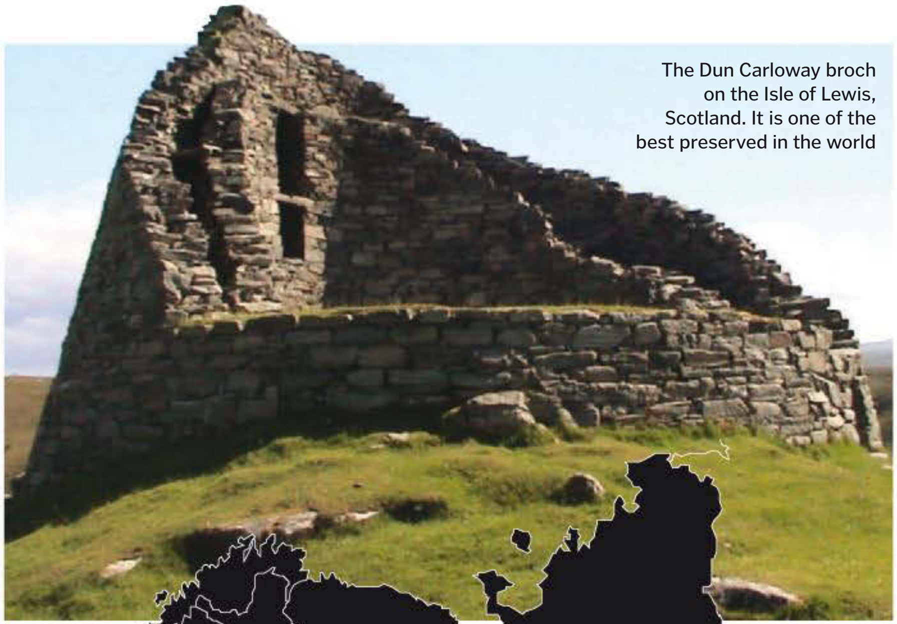
DID YOU KNOW? *The Celts didn't have a writing system, so much of what we know comes from artwork and secondary accounts*

There were other types of settlements

Hill forts were the most common type of settlement in Celtic Britain, but there were other types of communities too. In Scotland, for instance, brochs were very common. Stone was more readily available than wood in the north so hollow dry stone towers were built. A structure known as a crannog was also popular on the side of the lochs of Scotland.

Hill forts themselves also differed across the British Isles. Where the terrain was not hilly, a plateau or valley fort had to rely on man-made defences for protection. Others were built on river confluences for water access while others were purposely constructed on coastlines. Last of all, some forts were not built with defence as a priority so had smaller walls and enclosures.

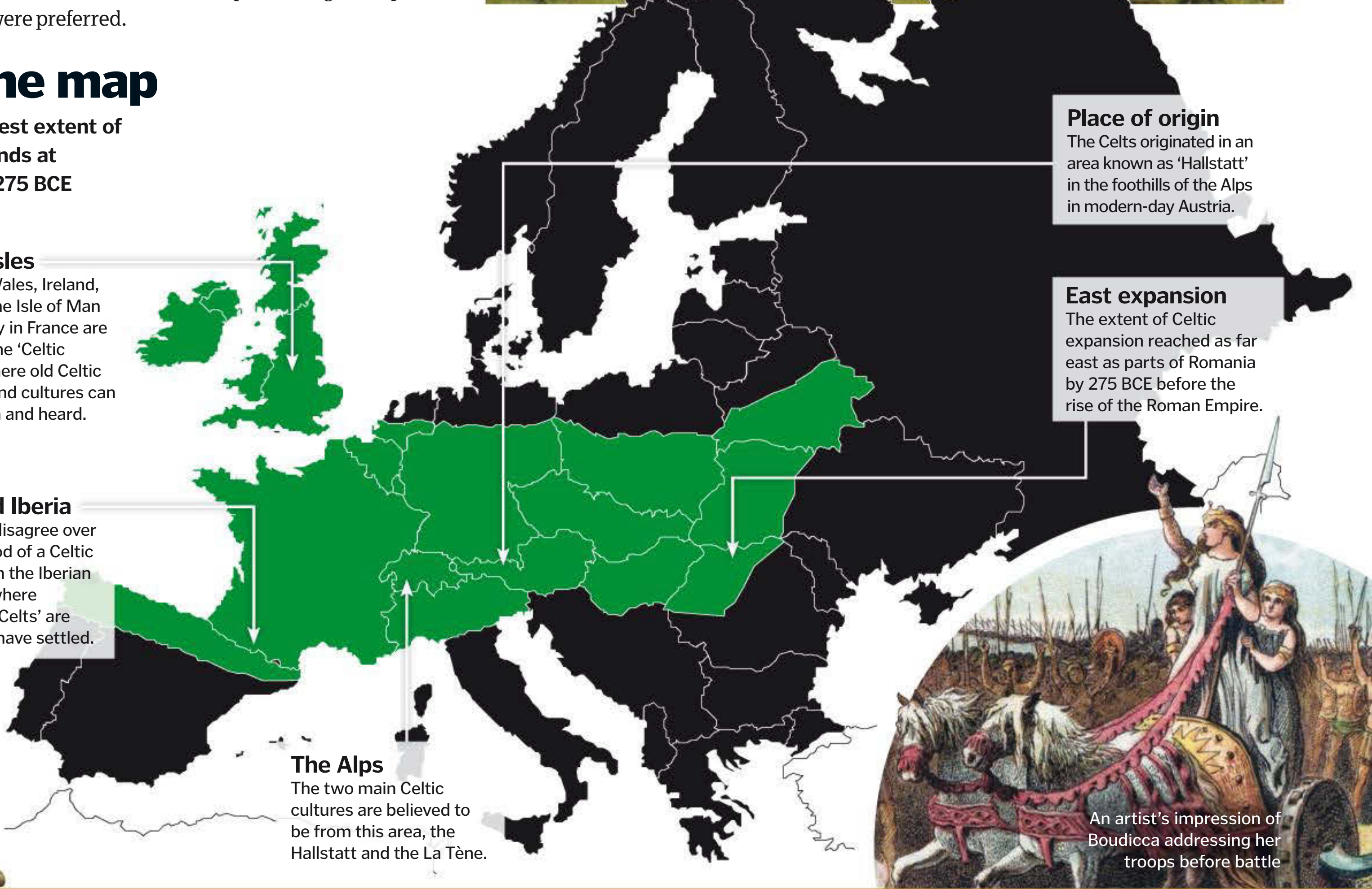
Even the buildings themselves differed, with Britain having roundhouses while in mainland Europe; rectangle or square buildings were preferred.



The Dun Carloway broch on the Isle of Lewis, Scotland. It is one of the best preserved in the world

On the map

🟩 **The largest extent of Celtic lands at around 275 BCE**



British Isles
Scotland, Wales, Ireland, Cornwall, the Isle of Man and Brittany in France are known as the 'Celtic Nations' where old Celtic traditions and cultures can still be seen and heard.

Gaul and Iberia
Historians disagree over the likelihood of a Celtic presence on the Iberian Peninsula where 'Lusitanian Celts' are thought to have settled.

The Alps
The two main Celtic cultures are believed to be from this area, the Hallstatt and the La Tène.

Place of origin
The Celts originated in an area known as 'Hallstatt' in the foothills of the Alps in modern-day Austria.

East expansion
The extent of Celtic expansion reached as far east as parts of Romania by 275 BCE before the rise of the Roman Empire.

An artist's impression of Boudicca addressing her troops before battle

Longer swords
As iron and steel production techniques gradually improved, longer, double-edged and better balanced swords became a popular weapon of choice in Celtic warfare.

Falcata sword
A typical Celtic sword used in the Iberian Peninsula. A short sword used for quick slashes, it delivered a powerful blow and could split enemy shields and helmets.

Armour
Known as Ceannlann, it was a mixture of linen and metal scales sewn onto chain mail armour. Nobles and rich Celts could afford this, while poor warriors wore leather armour or none at all.

Ranged weapons
The Celtic infantry focused on close-quarters combat, but after witnessing Viking bows, they began to occasionally use slings, bows and spears for attacks from a distance.

© Alamy; Corbis; Look and learn; Sol90; Thinkstock

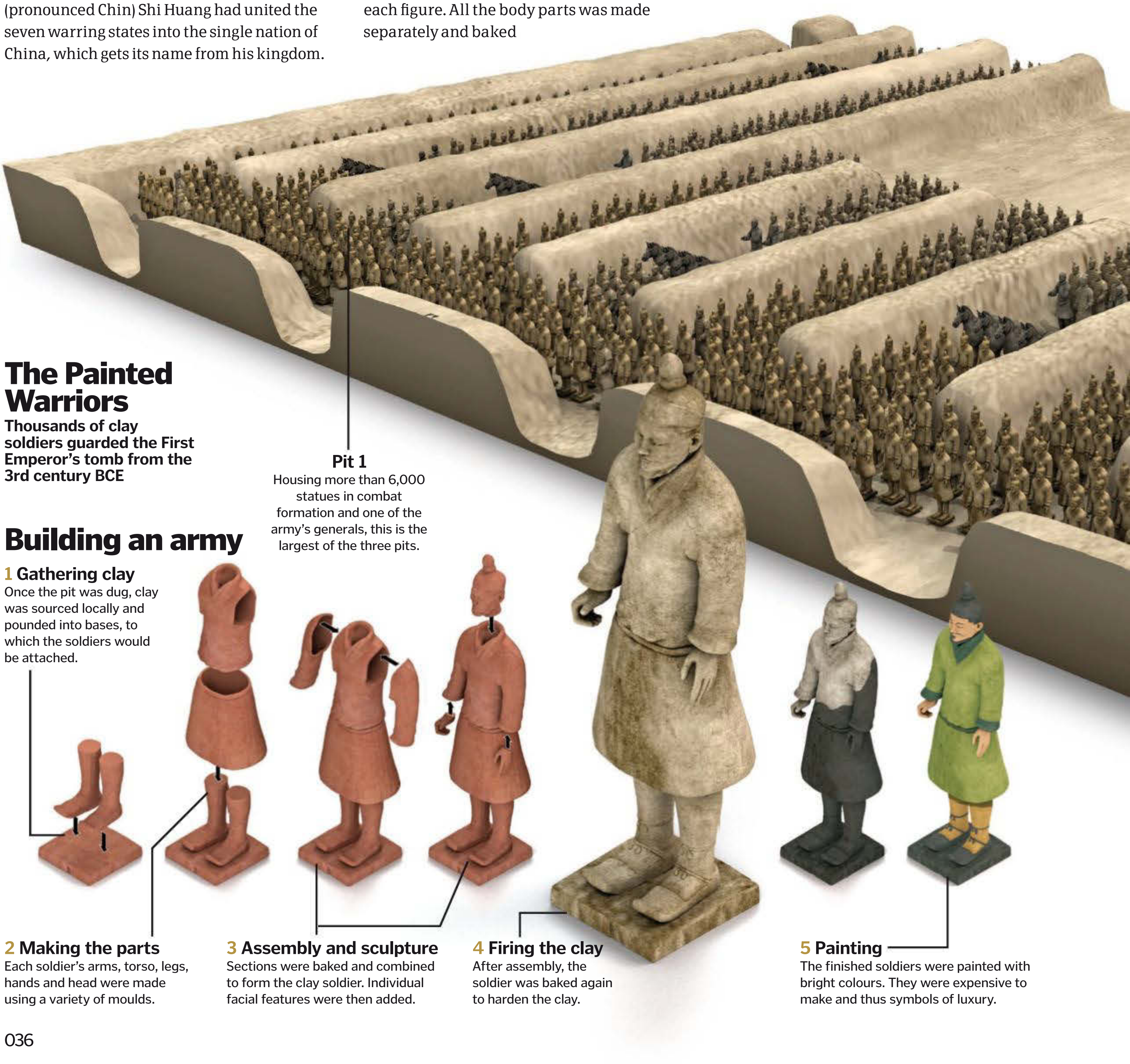
The Terracotta Army

Learn about China's ancient warriors for the afterlife

The eighth wonder of the Ancient world was discovered by accident. In 1974 in Xi'an, China, a group of farmers were digging when they uncovered a pit containing thousands of life-size warrior statues. The Terracotta Armyis part of an enormous mausoleum, built to accompany the First Emperor into the afterlife.

Over 2,000 years ago, Emperor Qin (pronounced Chin) Shi Huang had united the seven warring states into the single nation of China, which gets its name from his kingdom. The resulting peace meant there was no use for his vast army, so he set them to work building his elaborate tomb.

Much like the whole of Chinese society at the time, the Emperor was obsessed with life after death. He believed that the next world mirrored this one, so commissioned an army of life-size clay warriors to help maintain his rule. The pits were excavated and clay bases were made for each figure. All the body parts was made separately and baked in a kiln before being joined, in an impressive early example of assembly-line construction. Once complete, each warrior was baked again at 1,000 degrees Celsius to harden the final structure. These advanced methods make that the Terracotta army is a lasting reflection of the ingenuity of early Chinese society.



The Painted Warriors

Thousands of clay soldiers guarded the First Emperor's tomb from the 3rd century BCE

Pit 1
Housing more than 6,000 statues in combat formation and one of the army's generals, this is the largest of the three pits.

Building an army

1 Gathering clay
Once the pit was dug, clay was sourced locally and pounded into bases, to which the soldiers would be attached.

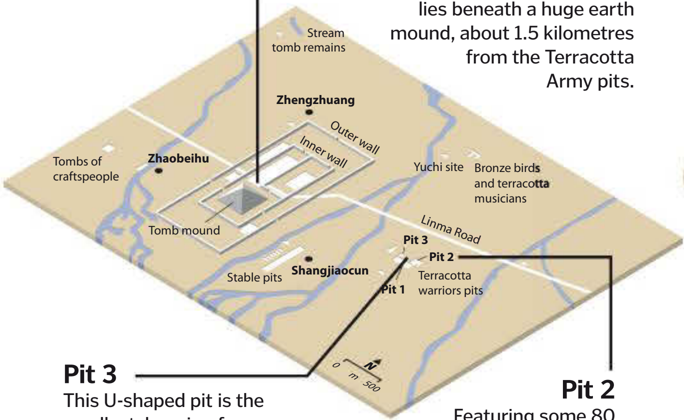
2 Making the parts
Each soldier's arms, torso, legs, hands and head were made using a variety of moulds.

3 Assembly and sculpture
Sections were baked and combined to form the clay soldier. Individual facial features were then added.

4 Firing the clay
After assembly, the soldier was baked again to harden the clay.

5 Painting
The finished soldiers were painted with bright colours. They were expensive to make and thus symbols of luxury.

DID YOU KNOW? *Emperor Qin ordered for many great buildings, including an early form of the Great Wall of China*

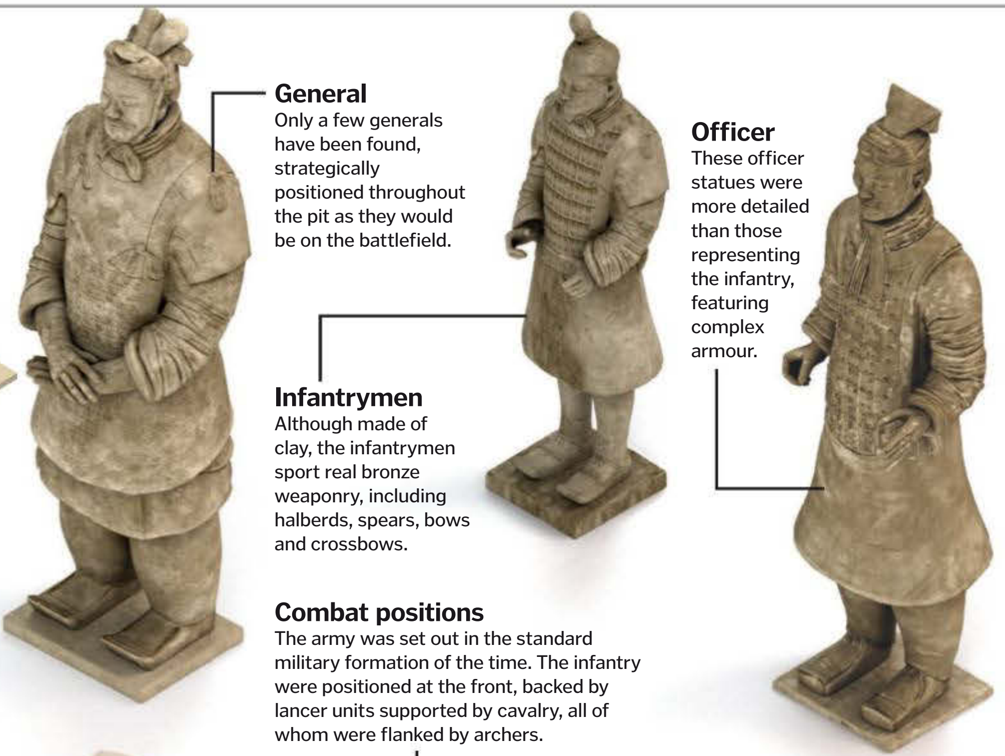


Stream
tomb remains
Zhengzhuang
Outer wall
Inner wall
Tombs of craftspeople
Zhaobeihu
Yuchi site
Bronze birds and terracotta musicians
Tomb mound
Linma Road
Pit 3
Pit 2
Terracotta warriors pits
Stable pits
Shangjiaocun
Pit 1
N
0 m 500

The mausoleum
The First Emperor's tomb lies beneath a huge earth mound, about 1.5 kilometres from the Terracotta Army pits.

Pit 3
This U-shaped pit is the smallest, housing fewer than 100 soldiers, four horses and a chariot.

Pit 2
Featuring some 80 chariots and an array of weaponry, this pit also contains some 160 kneeling archers.

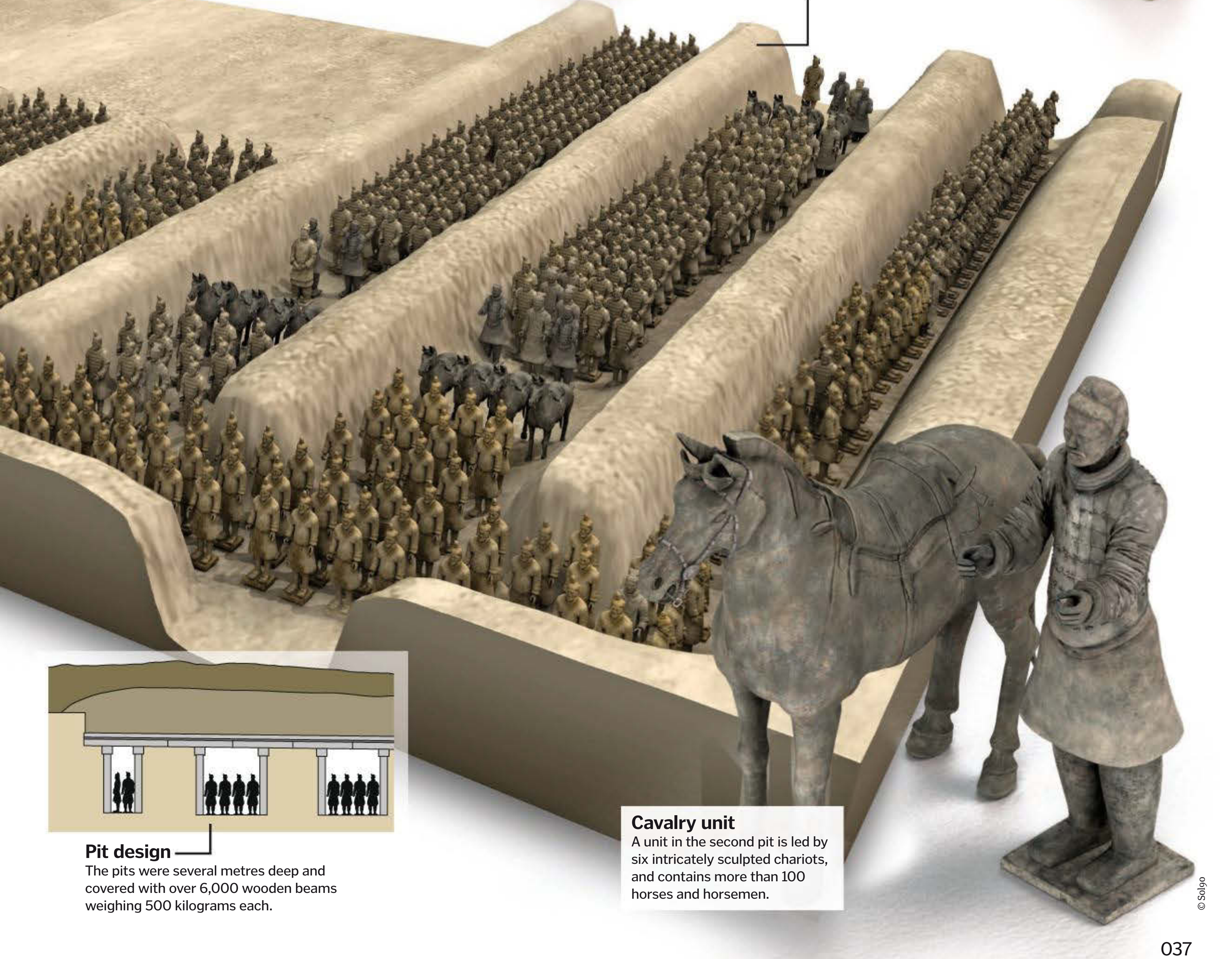


General
Only a few generals have been found, strategically positioned throughout the pit as they would be on the battlefield.

Infantrymen
Although made of clay, the infantrymen sport real bronze weaponry, including halberds, spears, bows and crossbows.

Officer
These officer statues were more detailed than those representing the infantry, featuring complex armour.

Combat positions
The army was set out in the standard military formation of the time. The infantry were positioned at the front, backed by lancer units supported by cavalry, all of whom were flanked by archers.



Pit design
The pits were several metres deep and covered with over 6,000 wooden beams weighing 500 kilograms each.

Cavalry unit
A unit in the second pit is led by six intricately sculpted chariots, and contains more than 100 horses and horsemen.

© Sol90

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© Thinkstock; Alamy

Exploring Machu Picchu

Perched precariously between two Peruvian peaks, the ancient Incan complex of Machu Picchu is truly one of Earth's wonders

Machu Picchu is a world-famous 15th-century palace complex, at an elevation of 2,430 metres (7,970 feet), built by the Incas. During its heyday it was ruled over by long-reigning king Pachacuti Inca Yupanqui. It is located between the two large mountain peaks of Machu Picchu – which translates as 'Old Peak' – and Huayna Picchu – or 'New Peak' – in the Cuzco region of Peru.

Despite the complex – which consists of over 300 buildings, terraces, plazas and a cemetery – being constructed in the mid-15th to early-16th centuries and well known to the local population, it only gained global fame in 1911, when American archaeologist Hiram Bingham stumbled across it while searching for Vilcabamba – the 'lost city of the Incas'.

Since its 'discovery' the complex has been extensively excavated as it was in a ruinous and overgrown state and today it is Peru's number one tourist attraction in terms of money generated. While excavations have unearthed lots of unique art, sculpture and architecture, as yet archaeologists are still to determine why the settlement was abandoned. The presence of an extensive aqueduct system throughout the site has led some scholars to believe a climate change-induced lack of water could have been a major factor.

DID YOU KNOW? *Machu Picchu was made a UNESCO World Heritage Site in 1983*

Machu Picchu
Peru
Brazil

© Thinkstock, Jordan Klein

Cardiff Castle

Why does Wales' most famous fortress look like something from a fairy tale?

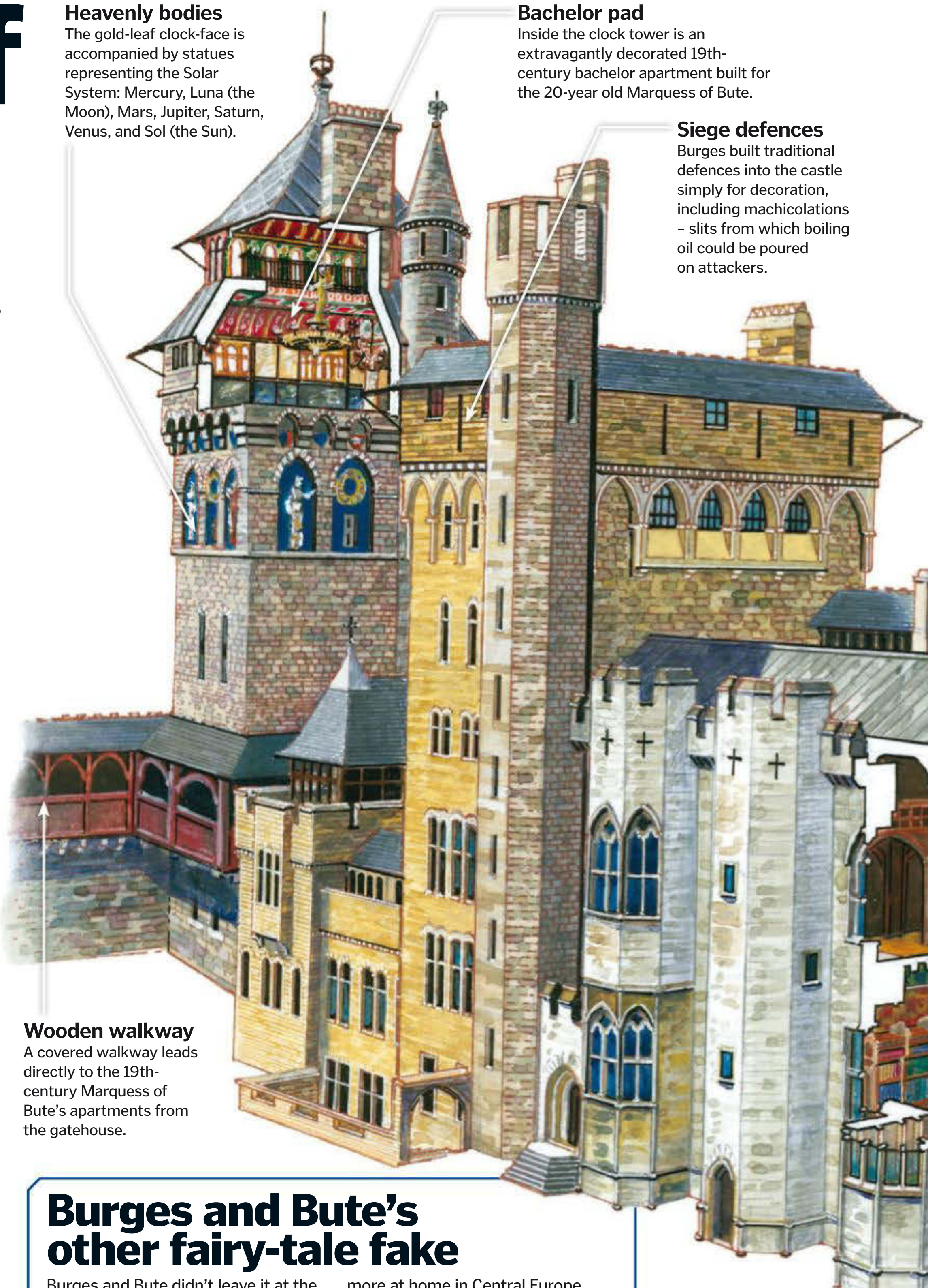
Adorned with elaborate sculptures, covered walkways and dominated by a striking clock tower, Cardiff Castle looks almost too good to be true. But it's real alright, and absolutely breathtaking.

Built sometime after 1081 over the ruins of a Roman fort by the Normans, who were then expanding from England into Wales, Cardiff Castle was extended in the following centuries, notably in the early-15th century, where the keep took shape, and in the 18th century, where it was embellished with a Georgian mansion.

In 1848, Cardiff Castle was inherited by John Patrick Crichton-Stuart, the third Marquess of Bute – then still not six months old – and its story soon took an unexpected swerve into the past. "My luxury is art", wrote Bute later. "I have considerable taste for art and archaeology, and happily the means to indulge them." Armed with his father's wealth and an eclectic taste in history, religion, art, literature and even the occult, the 18-year-old Bute struck up a friendship with famously eccentric architect and designer William Burges. The two began to rebuild and decorate Cardiff Castle to fit their dream view of how a medieval castle should look.

Extensively remodelling the interior with cheeky carvings, stained glass, angelic statues and vaulted ceilings, Burges dwarfed the original building with Bute's new apartments in a 40-metre (130-foot) high clock tower decorated with the various symbols of the Zodiac.

Sadly, Burges died in 1881 before his finest work yet – the breathtaking Arab Room, inspired by his travels to Sicily and Turkey – was complete and Bute paid tribute to his "soul-inspiring" friend in marble, carving both of their names where they can still be seen amid the fairy-tale fantasy of Cardiff Castle by stunned visitors today.



Heavenly bodies
The gold-leaf clock-face is accompanied by statues representing the Solar System: Mercury, Luna (the Moon), Mars, Jupiter, Saturn, Venus, and Sol (the Sun).

Bachelor pad
Inside the clock tower is an extravagantly decorated 19th-century bachelor apartment built for the 20-year old Marquess of Bute.

Siege defences
Burges built traditional defences into the castle simply for decoration, including machicolations – slits from which boiling oil could be poured on attackers.

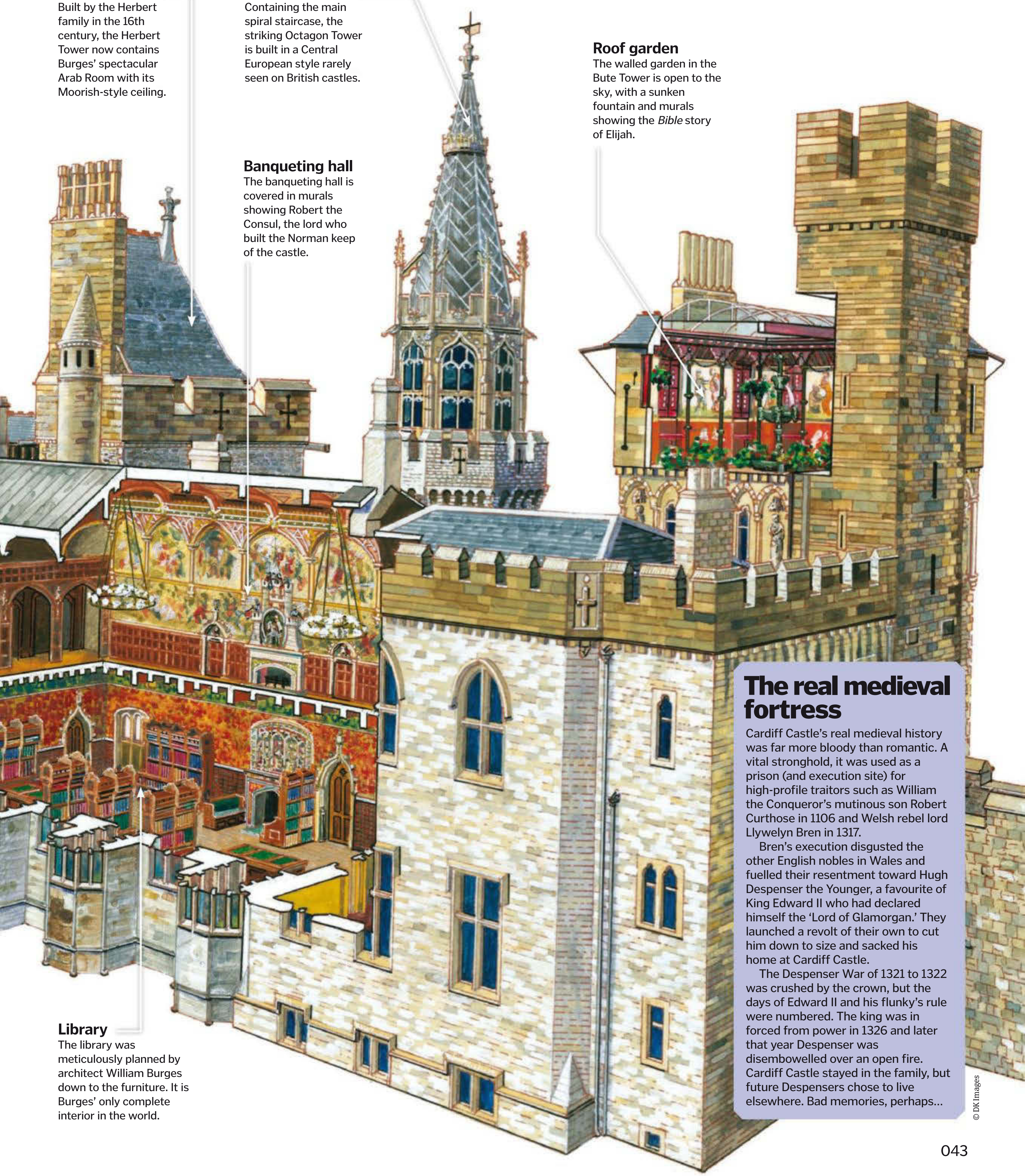
Wooden walkway
A covered walkway leads directly to the 19th-century Marquess of Bute's apartments from the gatehouse.

Burges and Bute's other fairy-tale fake

Burges and Bute didn't leave it at the one castle; they built a whole new one almost entirely from scratch in Tongwynlais, north of Cardiff, which was to serve as the Marquess' summer home.

After clearing the weeds and debris away from the ruins of the 13th-century Castell Coch (Welsh for 'Red Castle') in 1871, construction began in 1875 and Burges 'rebuilt' the castle with three historically dubious coned towers and covered wooden walkways that would look more at home in Central Europe. That Southern Wales.

Once past the portcullis and drawbridge, the interiors match Cardiff Castle for ostentation and Castell Coch has been used by TV series such as *Merlin*, *Doctor Who*, and *Da Vinci's Demons*. A 1954 *Welsh Office Official Handbook* describes Castell Coch as a "gigantic sham, a costly folly erected by an eccentric Victorian architect to satisfy the antiquarian yearnings of a wealthy nobleman." Ouch!



Herbert Tower
Built by the Herbert family in the 16th century, the Herbert Tower now contains Burges' spectacular Arab Room with its Moorish-style ceiling.

Octagon Tower
Containing the main spiral staircase, the striking Octagon Tower is built in a Central European style rarely seen on British castles.

Roof garden
The walled garden in the Bute Tower is open to the sky, with a sunken fountain and murals showing the *Bible* story of Elijah.

Banqueting hall
The banqueting hall is covered in murals showing Robert the Consul, the lord who built the Norman keep of the castle.

Library
The library was meticulously planned by architect William Burges down to the furniture. It is Burges' only complete interior in the world.

© DK Images

The real medieval fortress

Cardiff Castle's real medieval history was far more bloody than romantic. A vital stronghold, it was used as a prison (and execution site) for high-profile traitors such as William the Conqueror's mutinous son Robert Curthose in 1106 and Welsh rebel lord Llywelyn Bren in 1317.

Bren's execution disgusted the other English nobles in Wales and fuelled their resentment toward Hugh Despenser the Younger, a favourite of King Edward II who had declared himself the 'Lord of Glamorgan.' They launched a revolt of their own to cut him down to size and sacked his home at Cardiff Castle.

The Despenser War of 1321 to 1322 was crushed by the crown, but the days of Edward II and his flunky's rule were numbered. The king was in forced from power in 1326 and later that year Despenser was disembowelled over an open fire. Cardiff Castle stayed in the family, but future Despensers chose to live elsewhere. Bad memories, perhaps…

Inside a Japanese castle

We find out how Himeji Castle – a 17th-century fortification – has stood firm despite several centuries of conflict and natural disasters

Built on a hill 45 metres (150 feet) above sea level in southern-central Japan, Himeji Castle has survived innumerable feudal battles, sieges, earthquakes and even a WWII bombing. While today it's famed as Japan's largest castle, construction of the original site began in 1333 with the building of a small fort. The fort wasn't turned into a castle stronghold until nearly 250 years later, towards the end of the civil war era. The addition of three moats and dozens of extra buildings – including three large towers and a huge, six-storey main keep, or tenshu – saw the striking white complex become one of the greatest Japanese castles ever built.

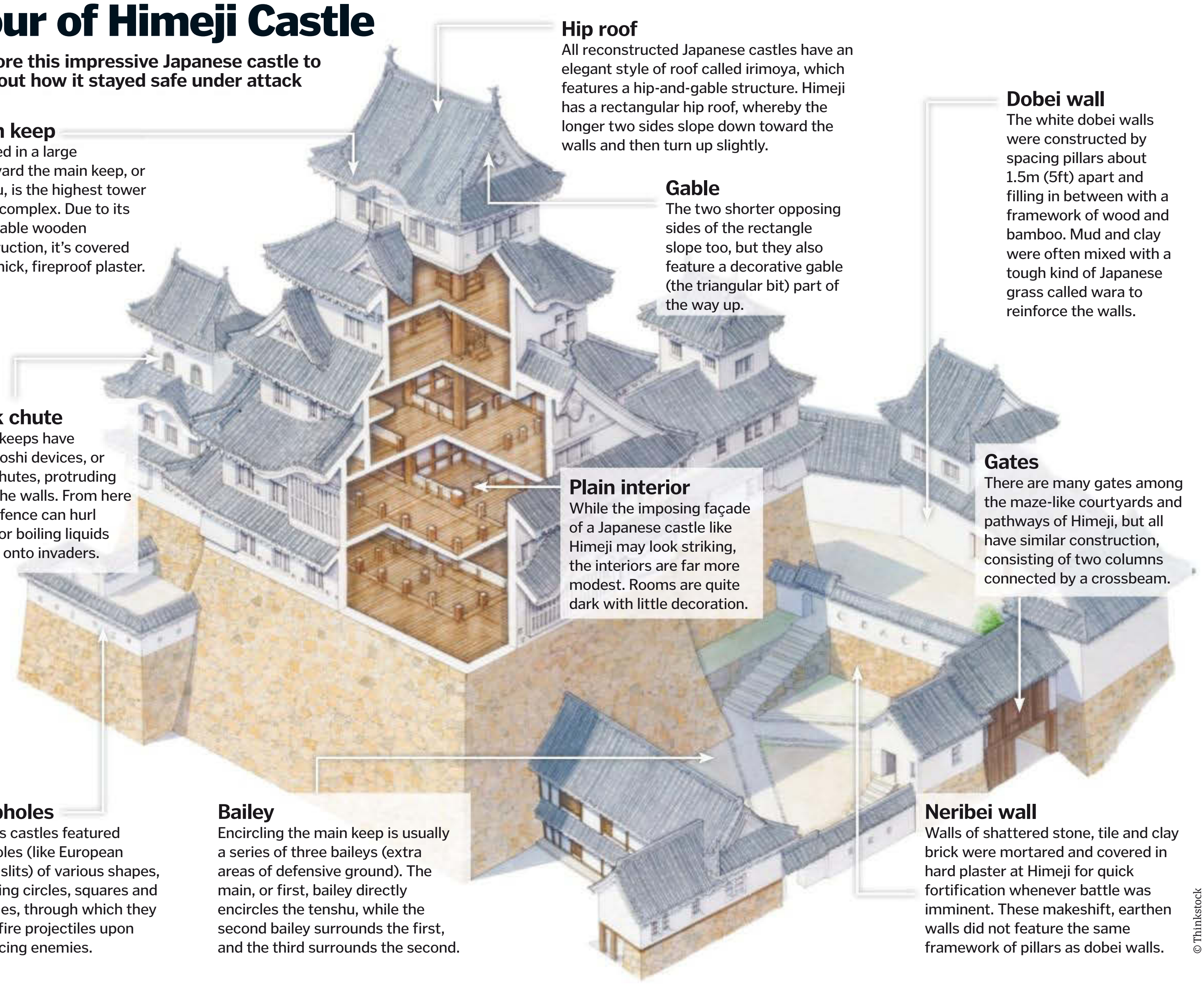
As is typical of traditional Japanese architecture, Himeji Castle is an elevated wooden structure featuring ornate tiling and embellishment. As well as gates, walls and other protective fixtures, Himeji and many other castles were equipped with a number of defensive devices to stall advancing foes.

Before they could even think about breaching the defences, the enemy would first have to navigate a frustrating maze of steep, snaking paths laid out around the castle walls. The physically demanding paths that seemed to lead directly to the main keep – but which often led instead to a dead-end – would disorientate and tire invaders. And even if they made it beyond the perimeter, the home team would then deploy an ingenious bevy of traps designed to outwit and injure the incoming aggressors, including conduits down which they would pour boiling oil or water.

Japan's best-preserved 17th-century castle, Himeji became a UNESCO World Heritage Site in 1993, which is quite remarkable considering what the region has endured, from earthquakes to attacks by US B-29 bombers. Of course, since the demolishment of the original 1333 fort, the castle has been rebuilt and remodelled by various rulers and architects, but what's interesting is that neither nature nor conflict has ever managed to get the better of Himeji.

Tour of Himeji Castle

Explore this impressive Japanese castle to find out how it stayed safe under attack



Main keep
Located in a large courtyard the main keep, or tenshu, is the highest tower in the complex. Due to its vulnerable wooden construction, it's covered with thick, fireproof plaster.

Hip roof
All reconstructed Japanese castles have an elegant style of roof called irimoya, which features a hip-and-gable structure. Himeji has a rectangular hip roof, whereby the longer two sides slope down toward the walls and then turn up slightly.

Gable
The two shorter opposing sides of the rectangle slope too, but they also feature a decorative gable (the triangular bit) part of the way up.

Dobei wall
The white dobei walls were constructed by spacing pillars about 1.5m (5ft) apart and filling in between with a framework of wood and bamboo. Mud and clay were often mixed with a tough kind of Japanese grass called wara to reinforce the walls.

Rock chute
Many keeps have ishi-otoshi devices, or rock chutes, protruding from the walls. From here the defence can hurl rocks or boiling liquids like oil onto invaders.

Plain interior
While the imposing façade of a Japanese castle like Himeji may look striking, the interiors are far more modest. Rooms are quite dark with little decoration.

Gates
There are many gates among the maze-like courtyards and pathways of Himeji, but all have similar construction, consisting of two columns connected by a crossbeam.

Loopholes
Japan's castles featured loopholes (like European arrow slits) of various shapes, including circles, squares and triangles, through which they could fire projectiles upon advancing enemies.

Bailey
Encircling the main keep is usually a series of three baileys (extra areas of defensive ground). The main, or first, bailey directly encircles the tenshu, while the second bailey surrounds the first, and the third surrounds the second.

Neribei wall
Walls of shattered stone, tile and clay brick were mortared and covered in hard plaster at Himeji for quick fortification whenever battle was imminent. These makeshift, earthen walls did not feature the same framework of pillars as dobei walls.

© Thinkstock

DID YOU KNOW? *In 1974 a statue in the pagoda was found to contain what's believed to be one of Buddha's original teeth!*

The Fogong Temple Pagoda

The oldest wooden pagoda in China today is an architectural marvel by anyone's standards

The pagoda, traditionally a tiered tower built of stone, brick or wood, originated in historic eastern Asia. Usually associated with Buddhism and used for the storing of relics and sacred writings, the pagoda's architectural form has since been adopted by other religions and modified for secular use throughout the world.

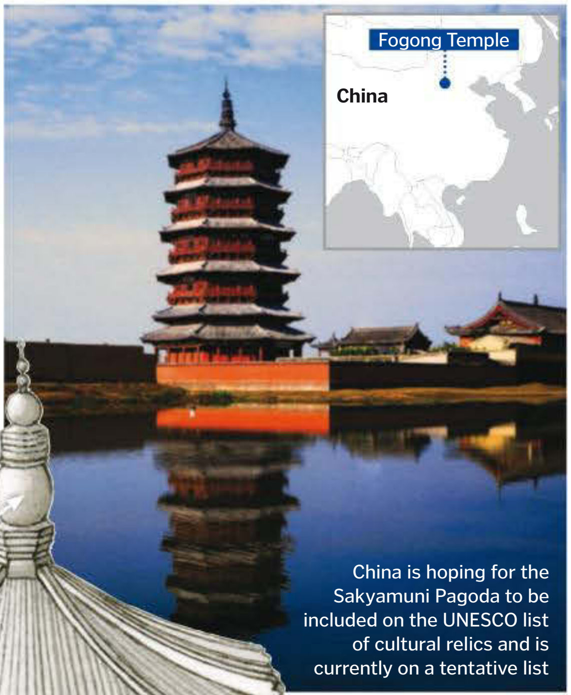
The Sakyamuni Pagoda of Fogong Temple forms the central element in a complex of buildings erected by the Chinese Emperor Daozong in 1056. Said to have been built on the site of his family home, the emperor was a devout Buddhist and demonstrated this through the erection of this remarkable wooden, nine-storey structure. Covered with a profusion of carved and painted decoration, the pagoda is supported by 24 exterior and eight interior pillars, and roofed with highly ornate and glazed ceramic tiles.

The pagoda has needed occasional minor repairs over its lifetime and, despite surviving numerous natural disasters, the only serious threat it has faced came during the Second Sino-Japanese War (1937-1945) when Japanese soldiers raked the structure with small-arms fire. Today, the Fogong Temple Pagoda is a popular tourist attraction rather than a religious site, but its cultural significance is recognised in both China and beyond.

Built to last

During the first 50 years of its existence, the Fogong Pagoda survived seven earthquakes. The reason for the building's resilience is both its design and building material. The key to its wooden construction is found in its slanting pillars, which act as both external and internal buttresses, and the 54 kinds of bracket arms used to create it. These interlocking sets of brackets, called 'dougong' in Chinese (literally 'cap and block'), provide increased support for the weight of the horizontal beams that span the pagoda's pillars by transferring the weight over a larger area.

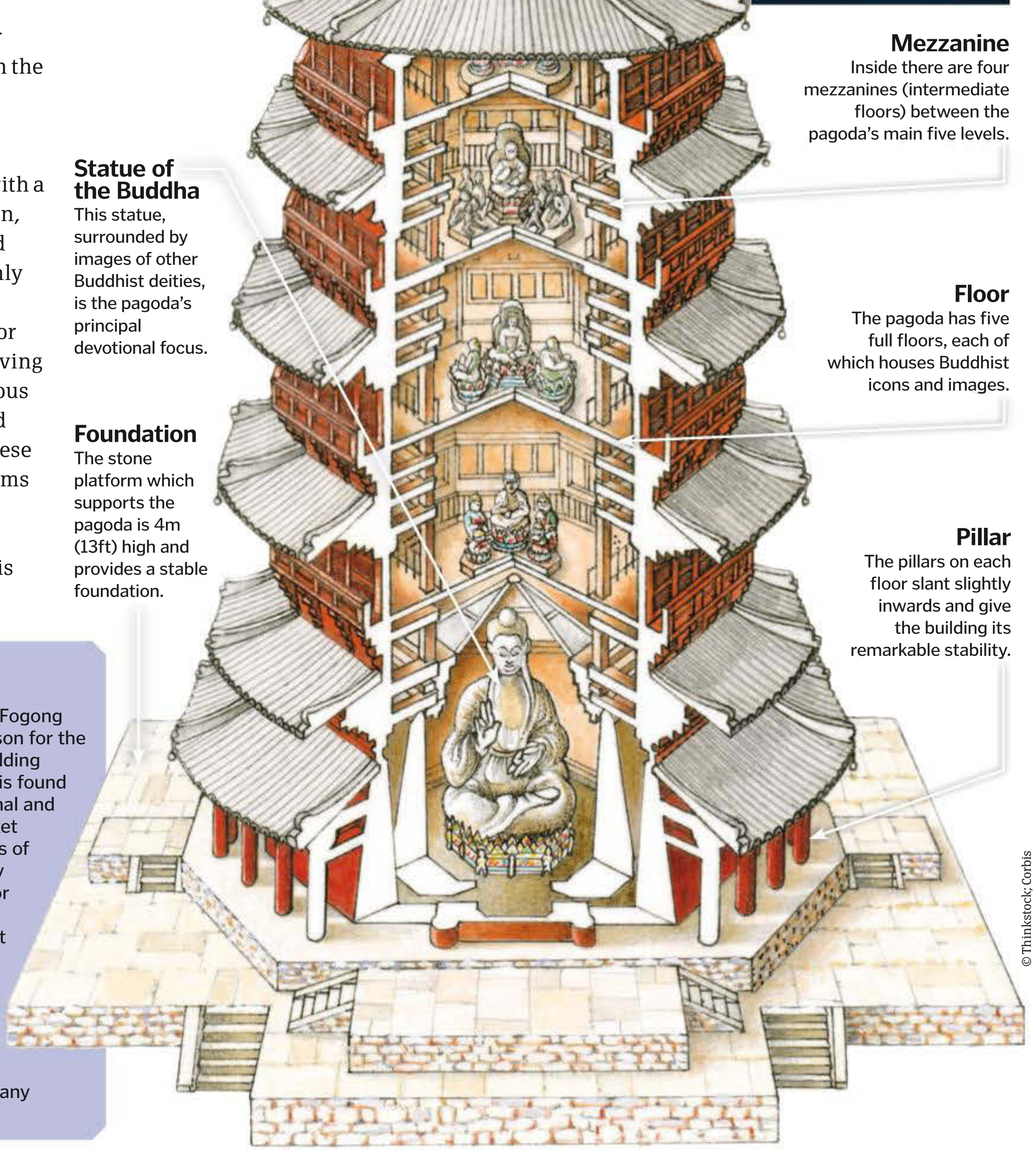
In this way a building consisting of many storeys may be constructed. Most importantly the use of multiple bracket arms allows structures to be elastic, which is how the Sakyamuni Pagoda has repeatedly withstood earthquakes that have flattened many of its neighbours.



China is hoping for the Sakyamuni Pagoda to be included on the UNESCO list of cultural relics and is currently on a tentative list

Anatomy of a pagoda

Examine the Sakyamuni Pagoda of Fogong Temple from top to bottom



Steeple
The steeple which surmounts the pagoda's roof is 10m (33ft) tall and serves as a lightning rod.

Statue of the Buddha
This statue, surrounded by images of other Buddhist deities, is the pagoda's principal devotional focus.

Foundation
The stone platform which supports the pagoda is 4m (13ft) high and provides a stable foundation.

Mezzanine
Inside there are four mezzanines (intermediate floors) between the pagoda's main five levels.

Floor
The pagoda has five full floors, each of which houses Buddhist icons and images.

Pillar
The pillars on each floor slant slightly inwards and give the building its remarkable stability.

© Thinkstock; Corbis

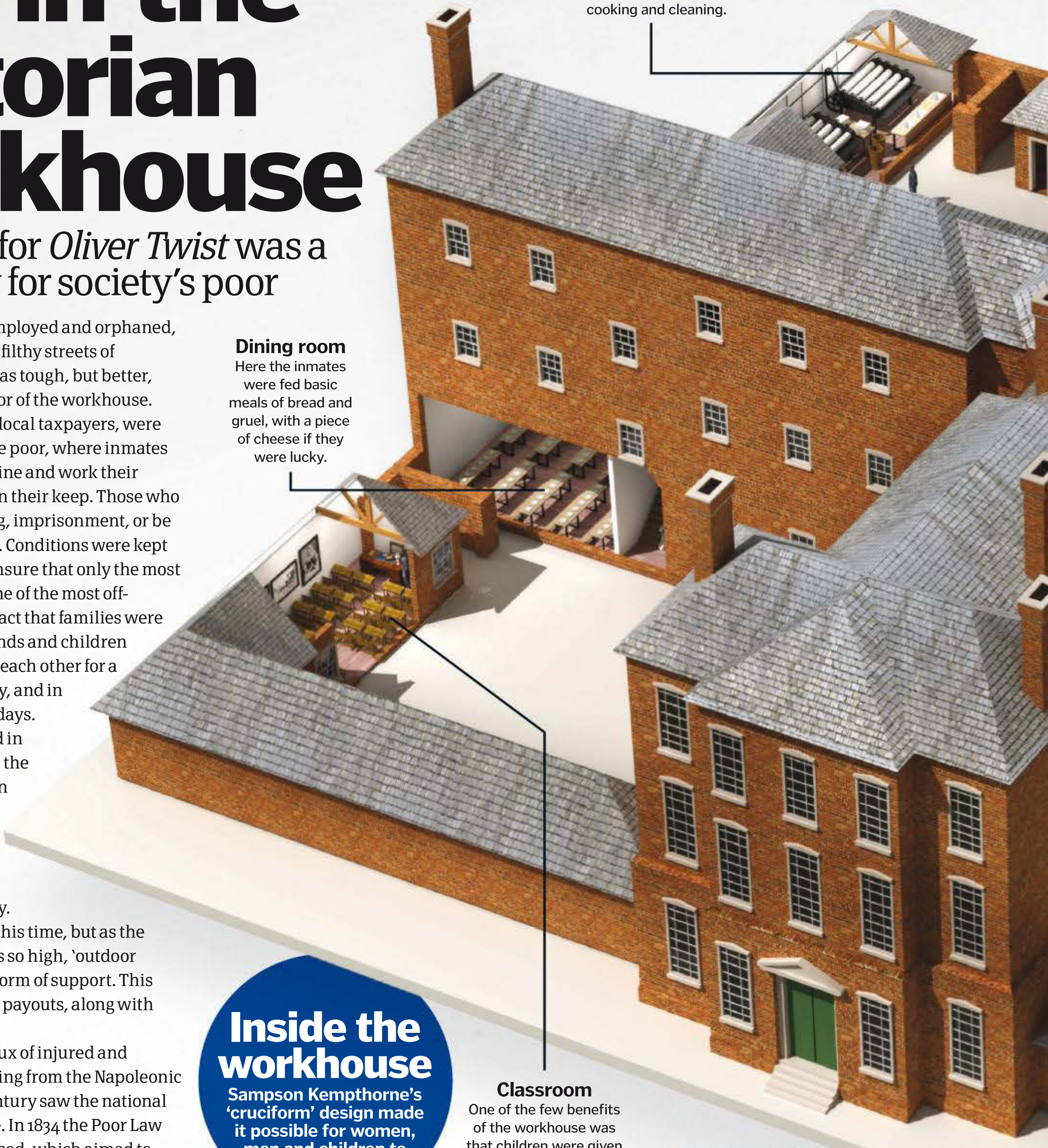
Life in the Victorian workhouse

The setting for *Oliver Twist* was a grim reality for society's poor

For the elderly, unemployed and orphaned, life on the cold and filthy streets of Victorian Britain was tough, but better, said many, than the horror of the workhouse. These homes, funded by local taxpayers, were essentially prisons for the poor, where inmates had to follow a strict routine and work their fingers to the bone to earn their keep. Those who didn't would face flogging, imprisonment, or be left on the street for dead. Conditions were kept deliberately meagre to ensure that only the most desperate applied, but one of the most off-putting aspects was the fact that families were separated. Wives, husbands and children were only allowed to see each other for a short 'interview' each day, and in worst cases, only on Sundays.

'Poor relief' has existed in England and Wales since the passing of the Poor Law in 1601, which gave parishes responsibility for looking after the most vulnerable among society. Workhouses did exist at this time, but as the cost of building them was so high, 'outdoor relief' became the main form of support. This usually consisted of cash payouts, along with food and clothing.

However, the huge influx of injured and unemployed men returning from the Napoleonic Wars in the early 19th century saw the national poor relief bill quadruple. In 1834 the Poor Law Amendment Act was passed, which aimed to end payouts to those able to work. Instead, relief would only be provided in the workhouses, except in special cases. For many penniless Victorians, it was the workhouse or nothing.



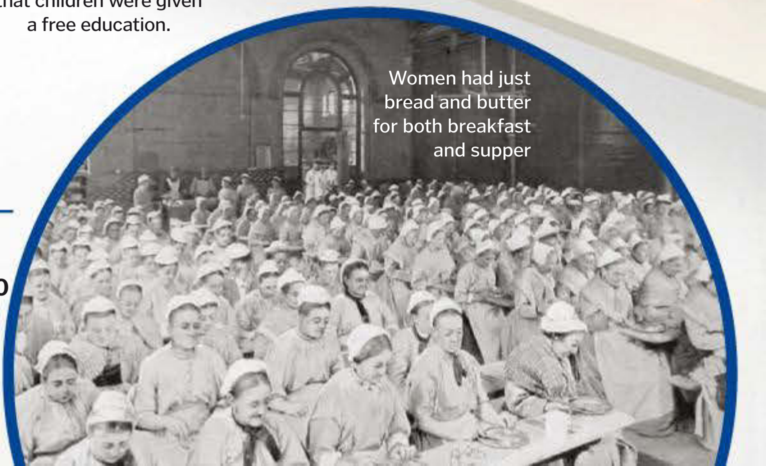
Laundry
Women were set to work doing domestic chores like washing, cooking and cleaning.

Dining room
Here the inmates were fed basic meals of bread and gruel, with a piece of cheese if they were lucky.

Classroom
One of the few benefits of the workhouse was that children were given a free education.

Inside the workhouse

Sampson Kempthorne's 'cruciform' design made it possible for women, men and children to be kept apart

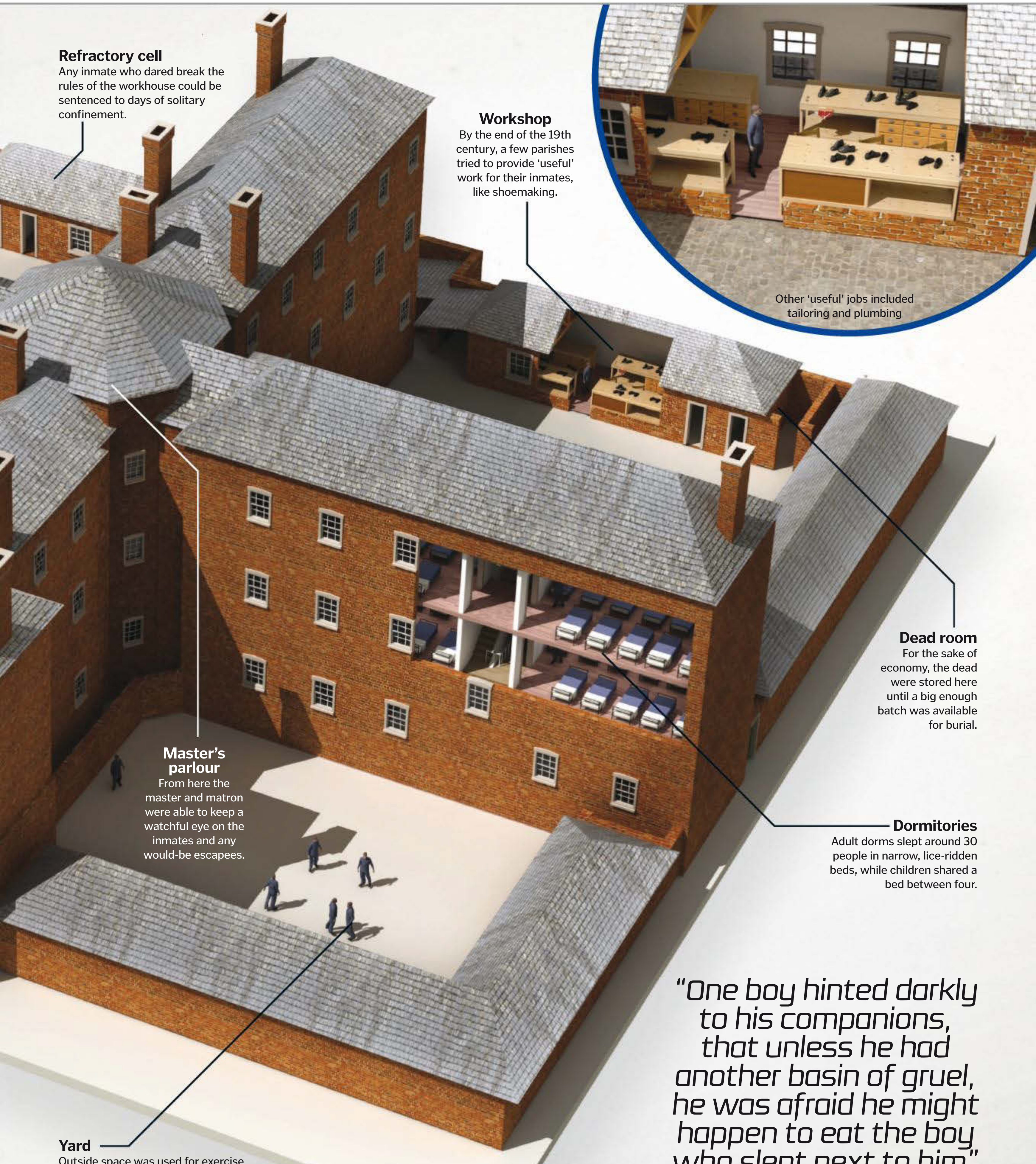


Women had just bread and butter for both breakfast and supper

Timeline of the daily routine

06:00	Wake up
06:30	Prayers and breakfast
07:00	Work/ lessons
12:00	Dinner
13:00	Work/ lessons
18:00	Prayers
19:00	Supper
20:00	Bed

DID YOU KNOW? *Silent movie star Charlie Chaplin grew up in a workhouse, but was one of few who managed to escape poverty*



Refractory cell
Any inmate who dared break the rules of the workhouse could be sentenced to days of solitary confinement.

Workshop
By the end of the 19th century, a few parishes tried to provide 'useful' work for their inmates, like shoemaking.

Other 'useful' jobs included tailoring and plumbing

Dead room
For the sake of economy, the dead were stored here until a big enough batch was available for burial.

Master's parlour
From here the master and matron were able to keep a watchful eye on the inmates and any would-be escapees.

Dormitories
Adult dorms slept around 30 people in narrow, lice-ridden beds, while children shared a bed between four.

Yard
Outside space was used for exercise or performing gruelling tasks like bone crushing and stone breaking.

> "One boy hinted darkly to his companions, that unless he had another basin of gruel, he was afraid he might happen to eat the boy who slept next to him"
>
> – *Oliver Twist* by Charles Dickens

Young inmates were taught reading, writing and arithmetic

Thomas Barnardo hung a sign outside his children's home saying: "No destitute child ever refused admission"

People ended up in the workhouse for many reasons. Usually, it was because they were too poor, old or ill to support themselves, perhaps because of high levels of unemployment or not having any family to look after them. Unmarried, pregnant women were often disowned by their families, and the workhouse was the only place they could go during and after the birth of their baby. Children who had not been born there often arrived after being orphaned, or if their father was admitted. Once inside, the whole family was split up, with men, women, boys and girls each going to a different section of the workhouse. The only exception was for children under seven, who in some cases were allowed to stay with their mothers in the female section.

Any inmate who was able to work faced day after day of gruelling and monotonous chores. Women mainly performed domestic jobs like cleaning, cooking and laundry. Some workhouses had workshops for sewing, spinning, weaving and other local trades, while others had vegetable gardens in which to grow produce for the kitchens. Both men and women slaved away picking oakum, which involved teasing out the fibres from old hemp ropes to be sold on to shipbuilders. Tasks given to men included stone-breaking, wood chopping and bone crushing to make fertiliser, although this was banned in 1845 after it was discovered that hungry inmates had resorted to eating the rotting flesh and marrow on the bones they were crushing. These were backbreaking and hand-blistering jobs, fuelled only by basic food rations of bread and gruel. By the end of the 19th century, a few unions were starting to provide 'useful' work for their inmates such as shoemaking, tailoring, bricklaying or plumbing.

Children seemingly had a better deal, as they were entitled to at least three hours of free school lessons every day – a luxury they would have been unlikely to receive in the outside world. They were taught reading, writing and arithmetic as well as what was described as "principles of the Christian religion," and other such instructions "as shall fit them for service, and train them to the habits of usefulness, industry and virtue."

However, the reality was that many workhouses were reluctant to spend money on even the most basic school equipment like writing slates, with many questioning why pauper children even needed to be taught literacy. The living conditions in which workhouse children grew up were appalling, with one visiting physician noting "the pale and unhealthy appearance of a number of children in the workhouse, in a room called the Infant Nursery. These children appear to be from two to three years of age; they are 23 in number; they all sleep in one room, and they seldom or never go out of this room, either for air or for exercise." In another part of the same

> "These were backbreaking and hand-blistering jobs, fuelled only by basic rations of bread and gruel"

On the menu

BREAKFAST

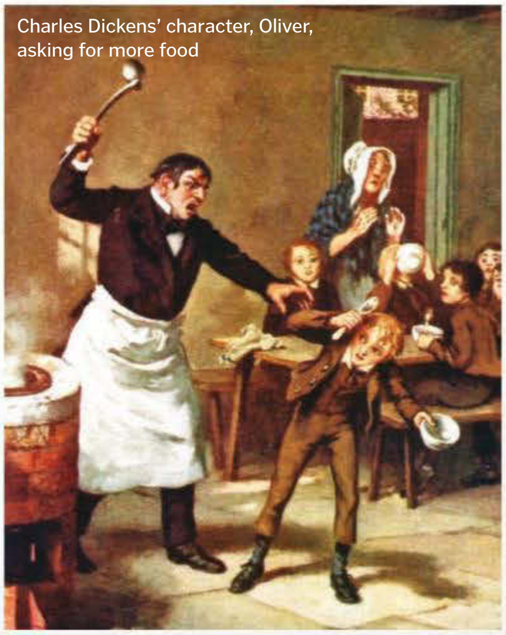
Bread, butter and tea for women; bread and gruel for men and children

DINNER

Soup, stew or boiled beef with bread and vegetables, with a pint of beer for adults and a half-pint for boys

SUPPER

Bread and butter or cheese,
with beer for men and boys,
tea for women and milk for girls



Charles Dickens' character, Oliver, asking for more food

DID YOU KNOW? *Until 1918, any citizens who received poor relief subsequently lost their right to vote*

workhouse, 104 girls slept four or more to a bed in a room just 27 x 5 metres in size.

Children were also subjected to abuse, many instances of which were reported by *The Times*, who were firmly against the new Poor Law. One report told of 13-year-old Elizabeth Danes, who after leaving some dirt in the corner of a room, was made to strip off her clothes, lie on a table, and be beaten with a broom until she bled.

One man would attempt to change all that. Thomas Barnardo was an Irish philanthropist who, while training to become a doctor in London, was horrified by the conditions that children there were living in. In 1870, he set up his first home for boys, where they were taught carpentry, metal work and shoemaking. At first Barnardo limited the number of boys allowed at the school, but after an 11-year-old boy who had been turned away was found dead, he decided that he would never do so again. By the time he died in 1905, the charity he founded had opened 96 homes caring for more than 8,500 children.

Despite their gloomy history, workhouses set the stage for a new era of state-funded welfare. When the NHS was founded in 1948, many former workhouses were transformed into hospitals.

Diary of a workhouse boy

Master made me go without supper tonight. Not that I care - you can't hardly taste that 'orrible gruel anyway. He said I'd stolen the answers to the spelling test again. I keep tryin' to tell him that it's 'cause Father taught me how to spell before he went off to war, but he won't listen to me. He gave me three lashes of the cane too, and this time it bled real bad. It's still throbbin'. I doubt I'll get much sleep tonight, but at least it'll take me mind off the bed bugs.

I wish Father were still alive. Then we wouldn't have ended up here. And I miss him 'orribly. I miss Ma and little Mary too. Master lets us see each other on Sundays, but it's only for an hour and there are always so many people runnin' round, cryin', shoutin', you can hardly hear yourself think. I miss how Sundays used to be, when Father would buy us each a sticky bun and we'd all eat it down by the river. But those days are long gone now.

Poor Ma, her arthritis is getting much worse. The matron makes her pick ropes apart all day, and her fingers can't take it. And Mary's headin' the same way, what with all that sewin' and mendin' they make her do. The bitter cold don't help much neither. It's all my fault. I'm the man of this family, I should be lookin' after 'em both. One day I'll get outta here and I'll make this family proud again. I swear it.

Children over the age of seven were separated from their mothers

Crime and punishment

Anyone who stepped out of line forfeited 'luxuries' like cheese, or faced solitary confinement

Neglect of work
No dinner and only bread for supper

Being noisy and swearing
Locked up for 24 hours with only bread and water

Fighting in school
No cheese for a week

Breaking a window
Sent to prison for two months

Running away
Lashes

Refusing to work
Sent to prison for 28 days

Refusing to attend Church
Next meal withheld

Drinking spirits or smoking
Next meal withheld

Playing cards or other games of chance
Items confiscated

Defacing or destroying the list of rules
Fed on bread and water only for two days

© WIKI; Alamy

Sagrada Família

Why is Spain's most iconic church still not finished after 130 years?

The statistics...

Sagrada Família

Length: 90m
Height: 170m
Area: 4,500m2
Spires: 18
Seats: 8,000
Visitors: 2 million per year

Sagrada Família is not a cathedral, because it doesn't have a bishop. But it was intended from the outset to be cathedral *sized*. The design calls for 18 spires, seven side chapels and three grand facades. The raised choir space has room for 1,100 singers and the six separate organs will be playable from a central console to give a single instrument with 8,000 pipes.

When it is completed, Sagrada Família will be the tallest church building in the world. But the extraordinary gingerbread architecture has divided opinion from the very beginning. George Orwell called it "one of the most hideous buildings in the world."

The church was commissioned by a pious bookseller called Josep Maria Bocabella and the first stone was laid in 1882. The Spanish architect Antoni Gaudí took charge of the design a year later. Because it has never received money from government or the Catholic Church, the pace of building work has always depended on the money that could be raised privately. During Gaudí's lifetime only the crypt, the apse above it and one of the spires had been completed. Gaudí himself was not concerned with the slow progress and famously said: "My client is not in a hurry."

Today, Sagrada Família is a UNESCO World Heritage Site and one of the most popular tourist attractions in Spain. The admission charge and other fund raising generates more than €25 million (£20 million), which now allows an extraordinary level of craftsmanship and detail on the construction. But Sagrada Família is not a museum piece. Modern construction techniques and materials are used wherever possible, including reinforced concrete, computer-aided design and 3D-printing of plaster decorations. Even though Antoni Gaudí himself lies buried in the crypt at Sagrada Família, a team of engineers, artists and craftsmen remain dedicated to finishing the work he began.

Construction ahead

The road toward completion of the Sagrada Família has been long and arduous – and there is still some way to go...

1882
Work begins under the architect Francisco de Paula del Villar y Lozano. It is originally designed as a Gothic revival church.

1883
Gaudí takes over after the original architect disagrees with the project promoter and resigns.

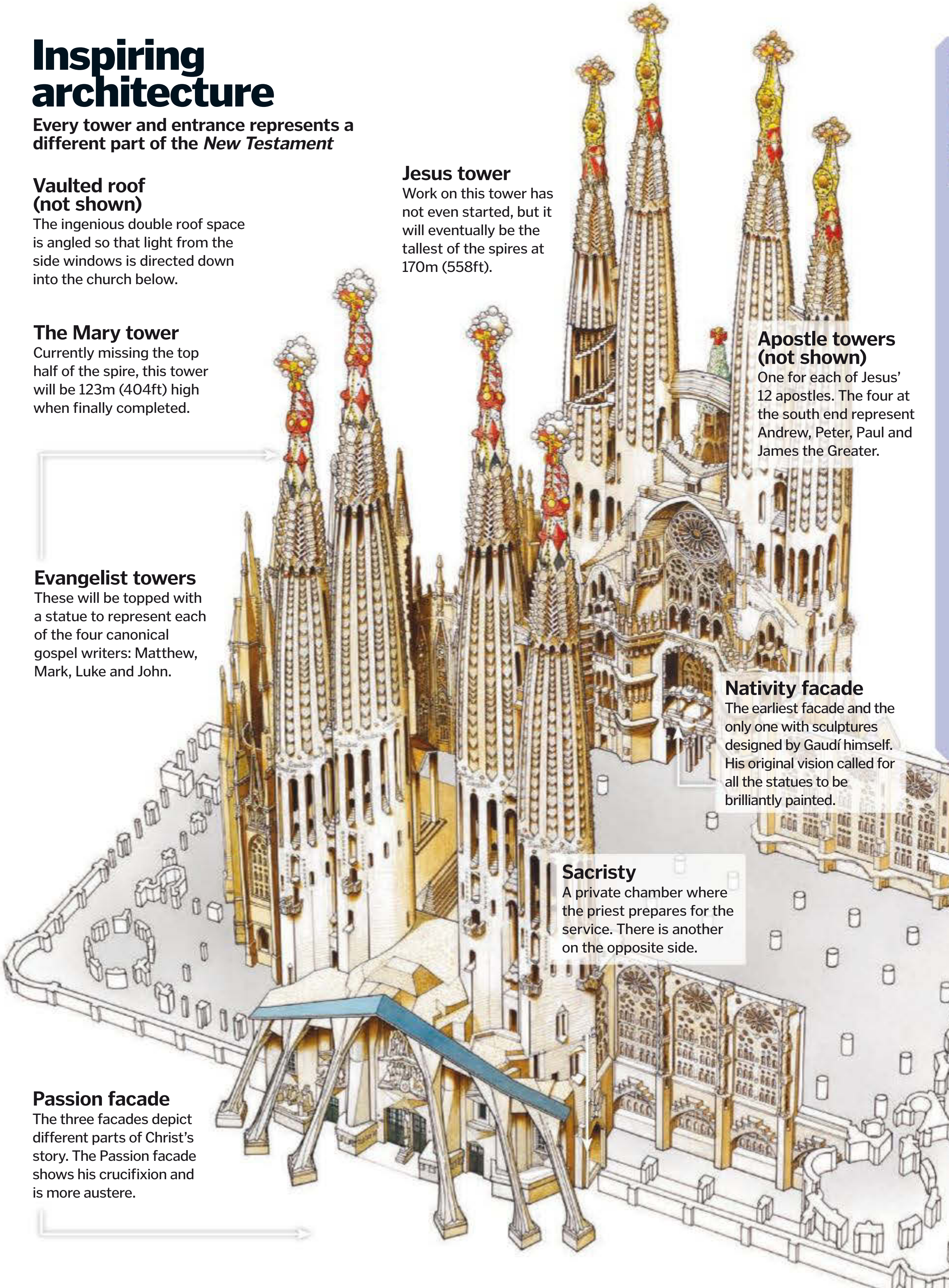
1894
More than a decade later, the crypt and apse (the semi-circular area behind the altar) are the first parts of the church to be finished.

1926
Gaudí dies, aged 74. He has spent over 42 years working on Sagrada Família, but more than 75 per cent of it is still unbuilt.

DID YOU KNOW? *The Jesus tower will be 1m (3.3ft) lower than Montjuïc Hill – Gaudí believed his creation should not exceed God's*

Inspiring architecture

Every tower and entrance represents a different part of the *New Testament*



Vaulted roof (not shown)
The ingenious double roof space is angled so that light from the side windows is directed down into the church below.

Jesus tower
Work on this tower has not even started, but it will eventually be the tallest of the spires at 170m (558ft).

The Mary tower
Currently missing the top half of the spire, this tower will be 123m (404ft) high when finally completed.

Apostle towers (not shown)
One for each of Jesus' 12 apostles. The four at the south end represent Andrew, Peter, Paul and James the Greater.

Evangelist towers
These will be topped with a statue to represent each of the four canonical gospel writers: Matthew, Mark, Luke and John.

Nativity facade
The earliest facade and the only one with sculptures designed by Gaudí himself. His original vision called for all the statues to be brilliantly painted.

Sacristy
A private chamber where the priest prepares for the service. There is another on the opposite side.

Gloria facade
Construction of this facade only began in 2002. It represents humanity's ascension to heaven and will eventually be the grandest of the three facades.

Passion facade
The three facades depict different parts of Christ's story. The Passion facade shows his crucifixion and is more austere.

Modern interior

Sagrada Família uses elaborate branching internal columns to direct all the weight of the building downward. This allows it to have a durable stone roof, instead of the traditional wooden design, and avoids the need for flying buttresses (which Gaudí called 'crutches') to prop up the walls on the outside. The shapes of the columns are modelled on twisting plant stems. At their base, each column begins as a polygon or star, and the number of sides or points doubles at intervals as the columns rise, until they all become cylinders at the top. The stained glass windows are another deliberate departure from traditional Catholic church design. Normally, the panes at the bottom are in lighter colours than those near the top, to give even illumination. At Sagrada Família it's the other way around. The windows at the top of the central nave are completely clear, to flood the vaults with light.

1933
The Nativity facade is finished. It is intended to set the standard for the structure and decoration of the rest of the church.

1936
The Civil War interrupts construction. Catalan anarchists burn down Gaudí's workshop. His models are destroyed.

1978
The four towers of the Passion facade are built and work starts on the facade itself.

1992
The Barcelona Olympics speed up funding by bringing in millions of extra tourists to the city.

2010
The roof of the central nave is completed and Pope Benedict XVI consecrates the basilica so it can be used for religious services at last.

2026
The aim is to have the church completed in time for the centenary of Gaudí's death – 144 years after work began.

© Getty; Alamy

Washington National Cathedral

What makes the USA's second-largest church its most important?

With its roots stretching back to the birth of the United States of America and construction lasting 83 years, Washington National Cathedral – also known as the Cathedral Church of Saint Peter and Saint Paul in the City and Diocese of Washington – is the historical and spiritual heart of the nation.

A "great church for national purposes" was first proposed in 1791, 15 years after the American colonies declared their independence from Great Britain, during the ambitious construction of Washington, DC, as a purpose-built capital for the proud new nation of the United States of America.

Though proposed during the administration of the first US president, George Washington, the foundation stone (taken from Bethlehem) on the English-style neogothic cathedral was eventually laid down over a century later, on 29 September 1907 in the presence of the 26th US president, Theodore Roosevelt. It was only officially completed on 29 September 1990, when the last decorative finial stone was installed in the presence of the 41st president, George HW Bush (the father of George W Bush).

The end result is more than 152 metres (500 feet) long from west to east and its central tower is just under 92 metres (302 feet) tall, making Washington National Cathedral the world's sixth-largest cathedral and the second largest in the United States.

Although the cathedral remained unfinished for much of the 20th century, the central Bethlehem Chapel was opened in 1912 for services, including the state funerals for presidents Dwight D Eisenhower, Gerald Ford and Ronald Reagan, and memorials for several other US presidents.

Washington National Cathedral also held memorials for important figures such as the first man on the Moon, Neil Armstrong, and former South African president Nelson Mandela, as well as during moments of national mourning such as the 11 September terrorist attacks in 2001 and the end of the Vietnam War.

What to look out for

From *Star Wars* to World War II, you'll find it all inside

Darth Vader
On the 'dark side' of the tower is a carved grotesque based on *Star Wars* villain Darth Vader, designed by 13-year-old Chris Rader in 1985.

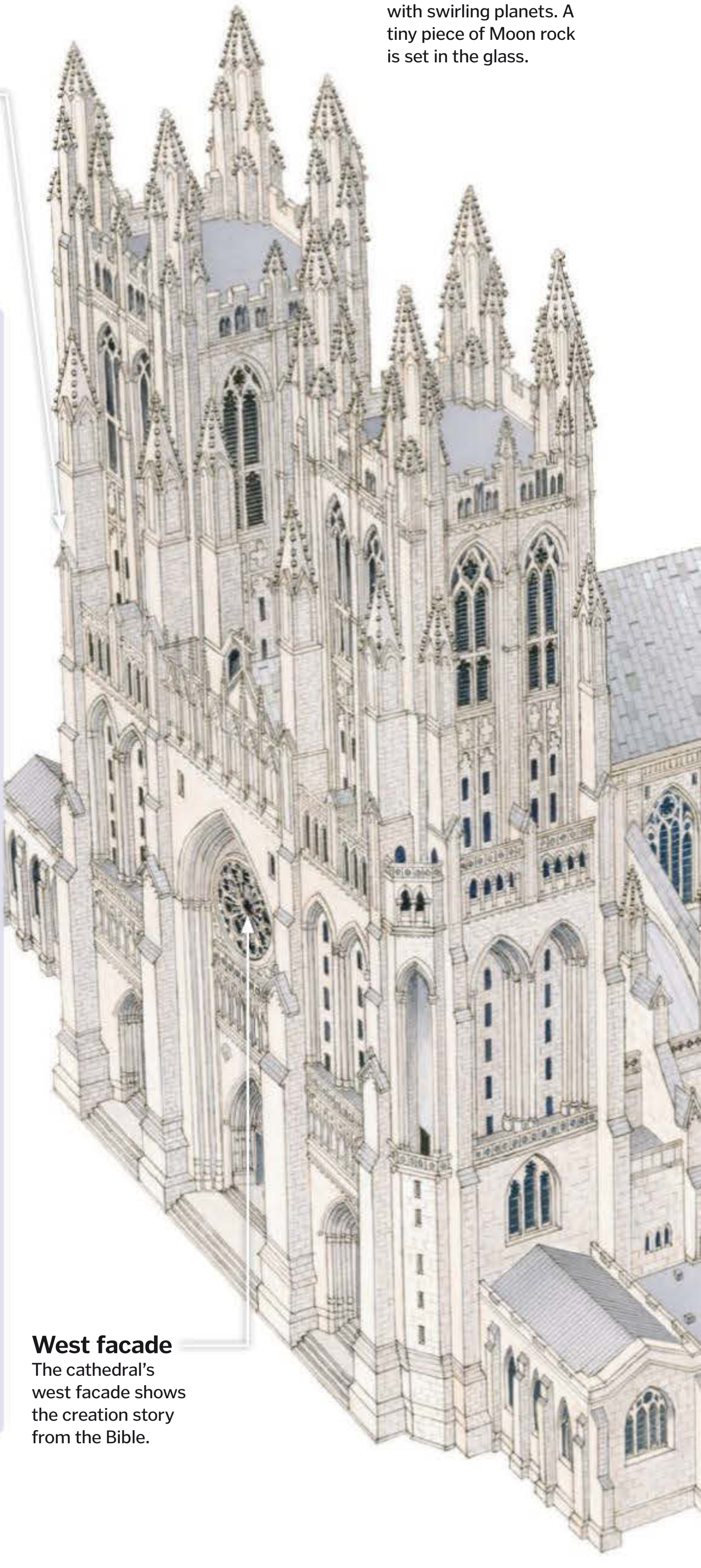
Cathedral Carousel

Not something you'd typically expect to find in the grounds of a church, the All Hallows Guild Carousel was built in the 1890s by the Merry-Go-Round Company of Cincinnati and was used in travelling county fairs across the States.

A rare all-wood carousel with a brass pipe organ, it has 24 hand-carved and brightly painted animals and two chariots for seating, which rise and fall as the carousel rotates around the centre pole, which is driven by a petrol engine.

It was purchased by the All Hallows Guild, the body that looks after the grounds of the Washington National Cathedral, in 1963 to bring a carnival atmosphere to open-air events. Now, the beautiful antique carousel is brought out only once a year and is on the National Register of Historic Places in its own right as one of only two all-wood carousels left in the United States.

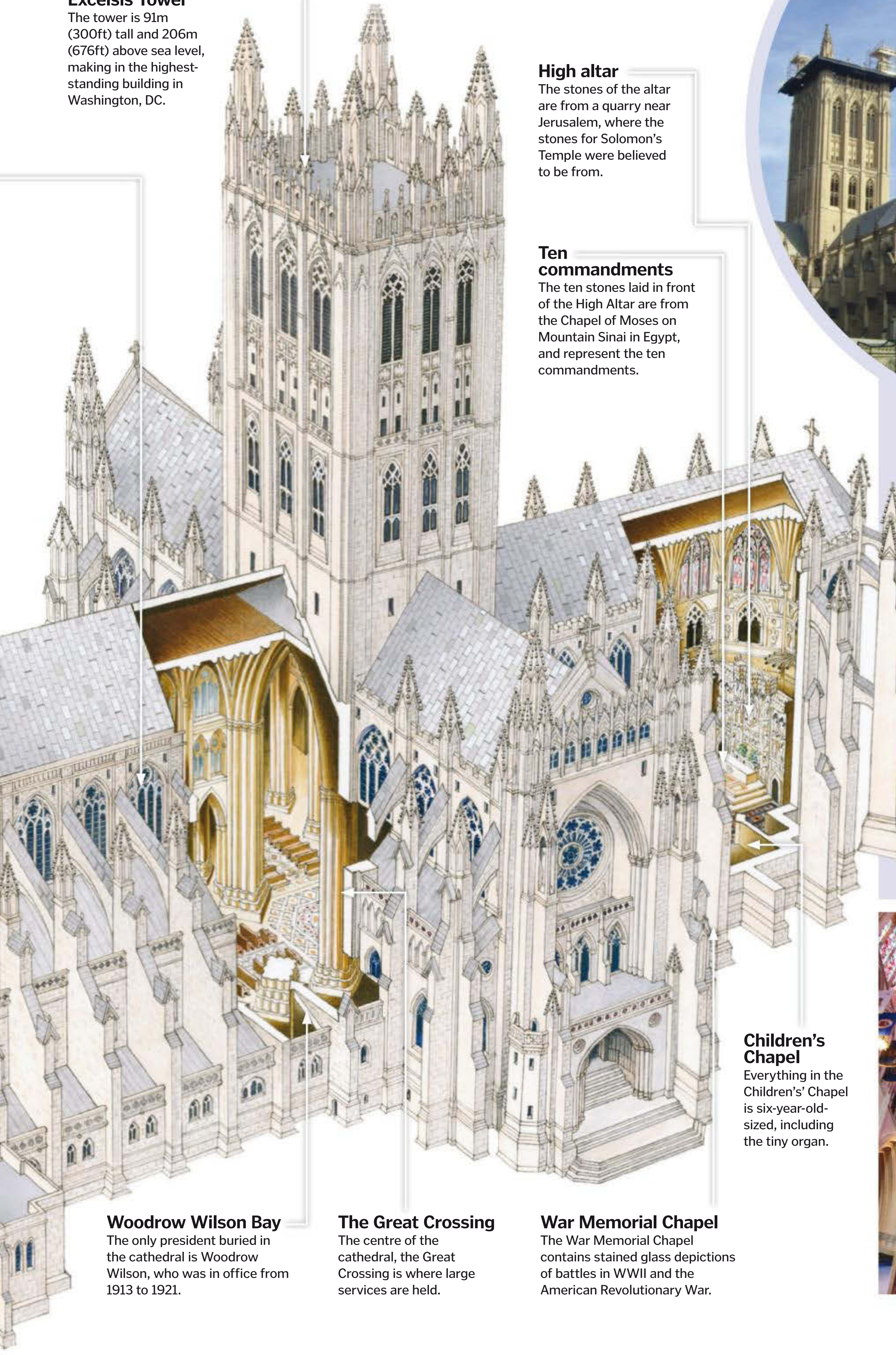
A beautiful hand-carved elephant on the All Hallows Guild Carousel



Space window
This stained-glass window commemorates the Apollo 11 mission with swirling planets. A tiny piece of Moon rock is set in the glass.

West facade
The cathedral's west facade shows the creation story from the Bible.

DID YOU KNOW? *Martin Luther King Jr delivered his last Sunday sermon at the cathedral on 31 March 1968. He was killed on 4 April*



Gloria In Excelsis Tower
The tower is 91m (300ft) tall and 206m (676ft) above sea level, making in the highest-standing building in Washington, DC.

High altar
The stones of the altar are from a quarry near Jerusalem, where the stones for Solomon's Temple were believed to be from.

Ten commandments
The ten stones laid in front of the High Altar are from the Chapel of Moses on Mountain Sinai in Egypt, and represent the ten commandments.

Children's Chapel
Everything in the Children's' Chapel is six-year-old-sized, including the tiny organ.

Woodrow Wilson Bay
The only president buried in the cathedral is Woodrow Wilson, who was in office from 1913 to 1921.

The Great Crossing
The centre of the cathedral, the Great Crossing is where large services are held.

War Memorial Chapel
The War Memorial Chapel contains stained glass depictions of battles in WWII and the American Revolutionary War.

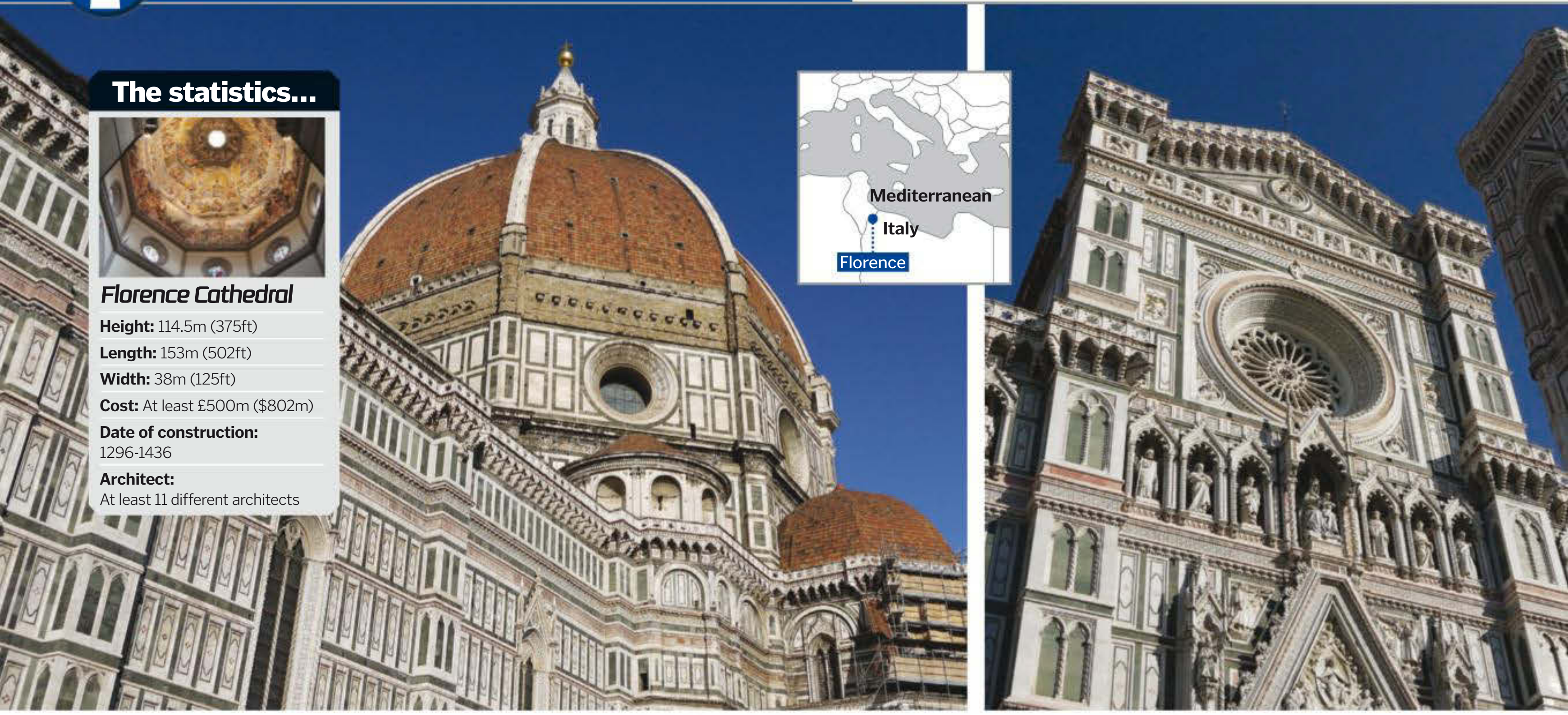
Cathedral vs quake

On 23 August 2011 the Washington National Cathedral was damaged by an earthquake. The 2011 Virginia Earthquake measured 5.8 on the Richter scale – the largest seen on the US east coast since 1944 and felt by more people than any other quake in US history.

Cracks appeared in the supporting buttresses surrounding the church, while three of the four stone spires on the central tower twisted out of alignment or broke off altogether and crashed through the roof.

The cathedral was closed until 7 November 2011 and repairs – expected to cost $26 million (£17 million) and not covered by the building's insurance – are ongoing.

© DK Images; Camila Ferreira & Mario Duran Ortiz



The statistics...

Florence Cathedral

Height: 114.5m (375ft)

Length: 153m (502ft)

Width: 38m (125ft)

Cost: At least £500m ($802m)

Date of construction: 1296-1436

Architect: At least 11 different architects

Florence Cathedral

Crowned with the largest masonry dome in the world, Florence Duomo is a Renaissance masterpiece

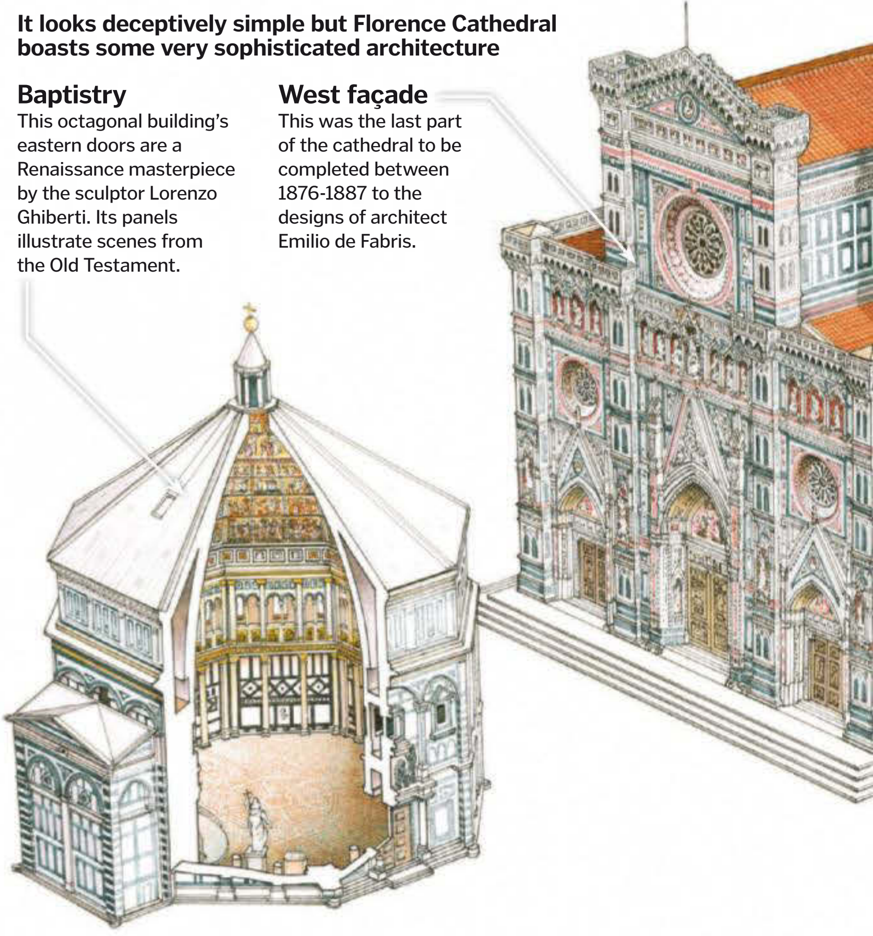
Popularly called the Duomo, Florence Cathedral's name is derived from the Latin 'domus dei' – the House of God – and is dedicated to the Virgin Mary Santa Maria del Fiore (St Mary of the Flower). The present building was started in 1296 and is the third cathedral to stand on the site. Taking 140 years to build, the original plan was only changed once during construction when the eastern half of the cathedral was massively expanded to allow for the now iconic dome. Work on this extraordinary structure began in 1420 and was completed in just 16 years. Higher and wider than any previously built, the octagonal dome was constructed without using a temporary wooden supporting frame. Consisting of a double shell made of sandstone, marble and brick, the base of the dome is about 52 metres (171 feet) above the ground and has a staggering 44-metre (144-foot) diameter.

The cathedral's exterior walls are faced in alternate vertical and horizontal bands of coloured marble – white from Carrara, green from Prato and red from Siena. Despite the many architects to work on it the building retains a remarkable architectural and aesthetic cohesion. The interior is sparsely decorated, but contains a number of major Renaissance artworks and 44 stained-glass windows – in fact, the largest expanse of glass installed during 14th and 15th-century Italy.

Above the main door is the basilica's one-handed liturgical clock, which shows all 24 hours. Erected in 1443, it is still working today. The largest cathedral in Europe when it was built, it has become symbolic of Florence and its dome is instantly recognised around the globe. Such is the Duomo's cultural importance that the cathedral complex was designated a UNESCO World Heritage site in 1982.

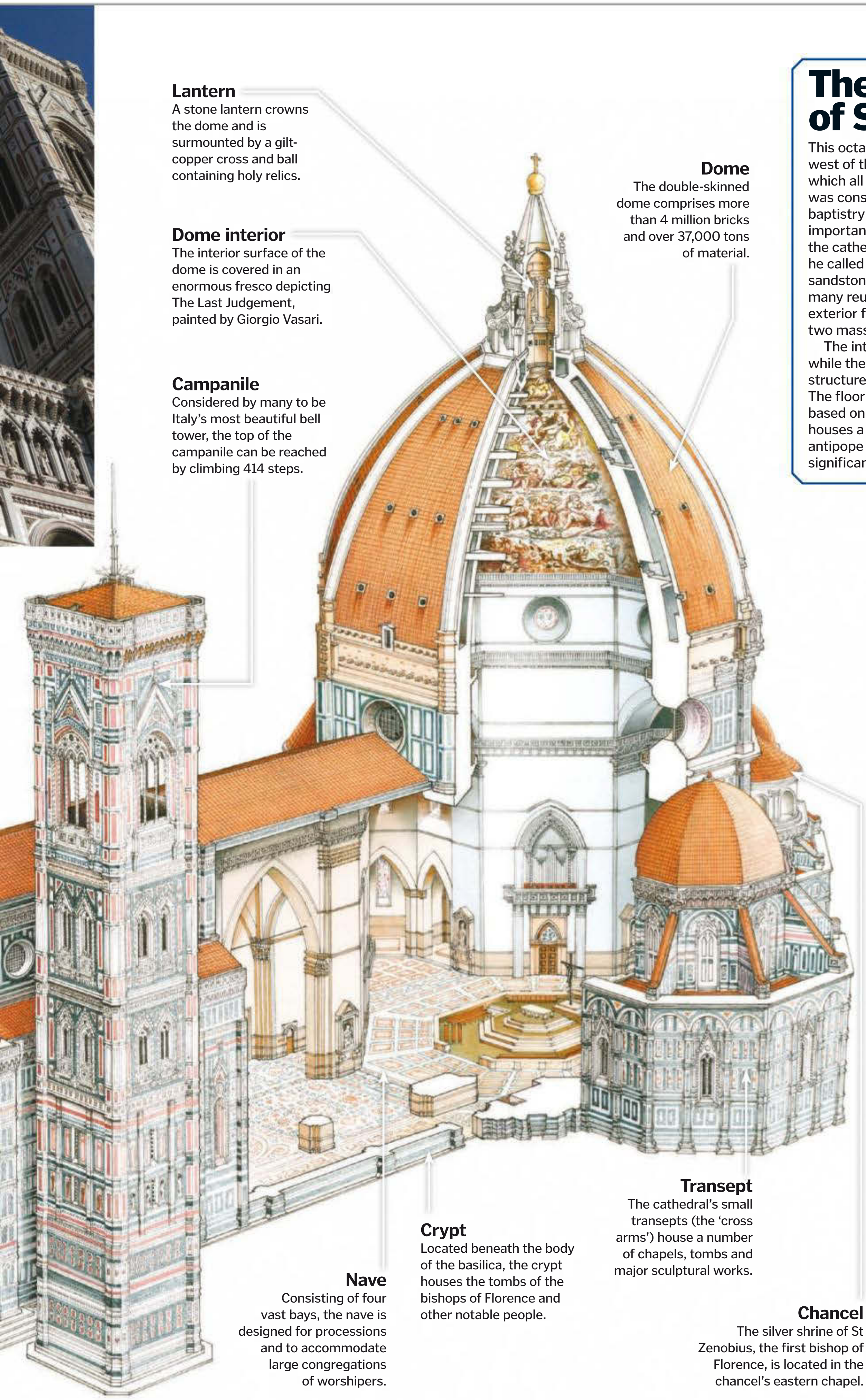
A tour of the basilica

It looks deceptively simple but Florence Cathedral boasts some very sophisticated architecture



Baptistry
This octagonal building's eastern doors are a Renaissance masterpiece by the sculptor Lorenzo Ghiberti. Its panels illustrate scenes from the Old Testament.

West façade
This was the last part of the cathedral to be completed between 1876-1887 to the designs of architect Emilio de Fabris.



Lantern
A stone lantern crowns the dome and is surmounted by a gilt-copper cross and ball containing holy relics.

Dome interior
The interior surface of the dome is covered in an enormous fresco depicting The Last Judgement, painted by Giorgio Vasari.

Campanile
Considered by many to be Italy's most beautiful bell tower, the top of the campanile can be reached by climbing 414 steps.

Dome
The double-skinned dome comprises more than 4 million bricks and over 37,000 tons of material.

Nave
Consisting of four vast bays, the nave is designed for processions and to accommodate large congregations of worshipers.

Crypt
Located beneath the body of the basilica, the crypt houses the tombs of the bishops of Florence and other notable people.

Transept
The cathedral's small transepts (the 'cross arms') house a number of chapels, tombs and major sculptural works.

Chancel
The silver shrine of St Zenobius, the first bishop of Florence, is located in the chancel's eastern chapel.

The Baptistry of St John

This octagonal building stands slightly to the west of the cathedral. Built to house the font in which all Christians in Florence were baptised, it was constructed between 1059 and 1128. The baptistry is famous for three sets of artistically important bronze doors. The eastern pair, facing the cathedral, so impressed Michelangelo that he called them the 'Gates of Paradise'. Made of sandstone and faced with marble incorporating many reused fragments of Roman buildings, the exterior features many sculptural groups and two massive porphyry columns.

The interior of the baptistry is clad in marble, while the inside of the dome which roofs the structure is inlaid with magnificent gold mosaics. The floor is covered in marble featuring a design based on the zodiac. Unusually, the baptistry also houses a number of tombs, including that of the antipope John XXIII which is considered a significant early-Renaissance sculptural work.

Giotto's campanile

The campanile, or bell tower, was designed by the celebrated painter Giotto di Bondone and it houses seven bells. Standing next to the cathedral, it is built from the same coloured marbles and so blends in well with its neighbour. The tower is square in plan with sides measuring 15 metres (47 feet) and it soars 87 metres (278 feet) high. Embraced by polygonal buttresses at its corners, it's divided into five separate levels – the upper three of which contain windows. Each of the three top levels is larger than the one below it in every dimension. These differences in size counter the effect of perspective so when viewed from below, the three top levels of the tower look equal in size. Although Giotto originally intended the campanile to be surmounted by a tall spire, after his death it was decided to build a large projecting terrace instead, which lends the tower a dramatic 'broken off' look.

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How was the Sistine Chapel's ceiling painted?

Explore the tools and techniques behind Michelangelo's lofty Renaissance masterpiece

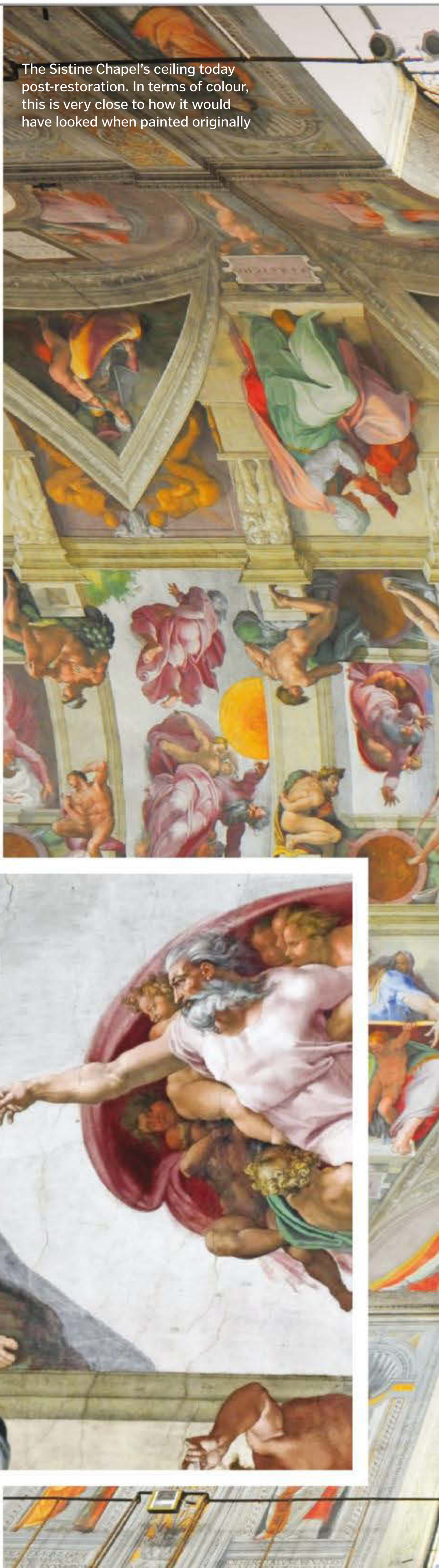
In painting the Sistine Chapel's ceiling in the early part of the 16th century Michelangelo had to overcome a number of daunting hurdles. The first comes directly from the physical properties of the ceiling, as it is a barrel vault, which is a curved surface. To make it more difficult still, that barrel vault is intersected with smaller vaults positioned over the windows. As such there are no flat surfaces anywhere except around the windows, where the artist also painted a series of half-moon-shaped lunettes. As a result, even prior to picking up a paintbrush Michelangelo had to first work out how to create realistic portrayals of human figures in proper proportion and in motion on these wildly uneven surfaces. His ability to pull this off is testament to his immense artistic skill.

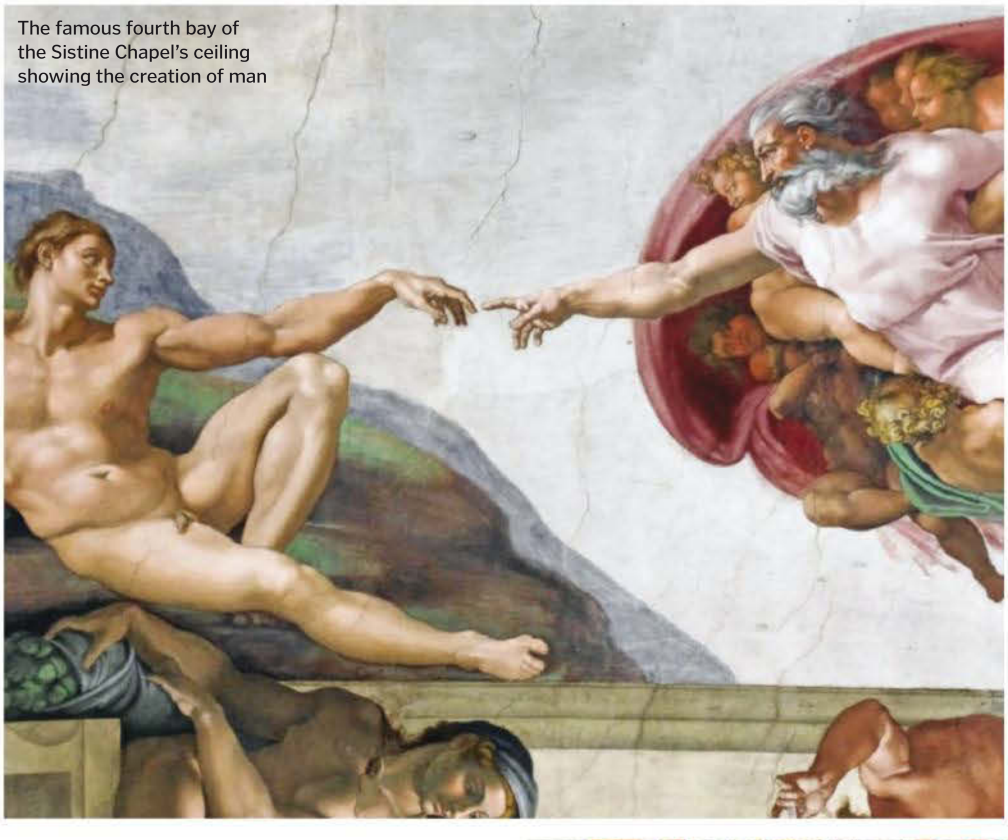
Another major challenge in painting the Sistine Chapel's ceiling was actually getting up there, as it is 20 metres (65 feet) above the floor. Fortunately, a conservation campaign that started in the Eighties revealed the method Michelangelo employed to reach such heights: he constructed a complex scaffold. The scaffold consisted of a truss bridge that spanned across the vault and ran on rails that were at a 90-degree angle to the walls. This permitted Michelangelo to access all areas of the ceiling as the scaffolding could be moved along the rails – it was only ever covering a quarter of the vault at any one time, as he needed ambient light from the windows to paint. Interestingly, the holes that supported this structure can still be seen in the walls to this day.

The third problem Michelangelo had to tackle was how to lay out the sketch lines for the entire ceiling. He did this by dividing the vault into various units by stretching chalked strings from one end of the chapel to the other (with help from assistants), before snapping them against the prepared plaster. In doing this, he laid out the linear structure of all the architecture, which is consistent throughout.

The last major obstacle that Michelangelo faced was the sheer scale of the project, which incredibly only took four years to complete. Painting the ceiling was a massive logistical undertaking and so he invited some of his friends from Florence to Rome to aid him.

As well as painting some of the recurring elements, such as columns and statues, these assistants helped him to build the scaffolding and mix/prepare the plaster, as well as lending a hand with the manufacture of paints, the trimming of paintbrushes and the sketching of full-sized drawings on paper for transferral onto the vault. This latter process involved the paper sketch being pressed against the ceiling, pricked with small holes around the outlines and then covered with black chalk dust to produce a dotted outline on the plaster.


The Sistine Chapel's ceiling today post-restoration. In terms of colour, this is very close to how it would have looked when painted originally


The famous fourth bay of the Sistine Chapel's ceiling showing the creation of man

DID YOU KNOW? *Michelangelo is one of many Masters to paint in the Sistine Chapel; others include Botticelli and Pinturicchio*

© Joe Angeles, Cambridge University Press/William Wallace

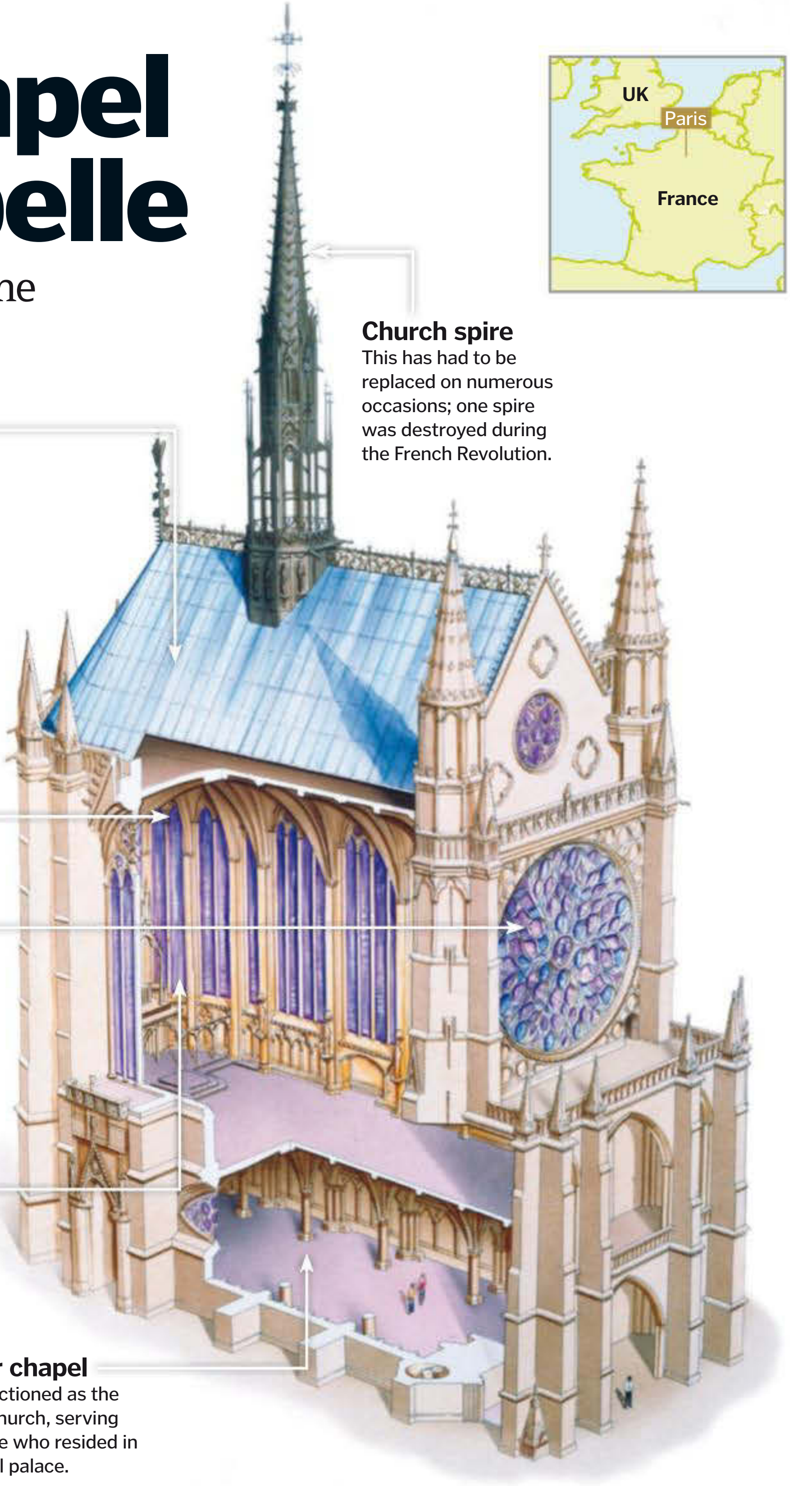
The Gothic chapel of Sainte-Chapelle

Built for King Louis IX, this church displays the finest example of Gothic stained glass

The Sainte-Chapelle, or 'Holy Chapel', was commissioned by King Louis IX of France more than 770 years ago to house his most prized possessions – what was believed to be the authentic 'crown of thorns' worn by Jesus Christ at his crucifixion, as well as fragments of the Holy Cross. The king bought these items and sought to build an appropriately elaborate church to display them in.

A stunning example of medieval architecture; nothing like this had ever been constructed before. The fact it was built between around 1241 and 1248 is even more incredible considering Notre Dame took more than 200 years to build from 1163. The church walls act as frames for the 15 immense stained glass panels. The stained glass mainly depicts famous Bible stories, including parts from the Old Testament. Also shown is the history of the holy relics, from their discovery by Saint Helen to their eventual arrival in the French Kingdom. Restorations of the stained glass in the 19th century remained faithful to the original designs, and further work is underway today to protect it from deterioration.

When we think of medieval architecture, many of us think of dark, dingy buildings. The Sainte-Chapelle defies this idea, with a majestic design that embraces the power of light to create a truly breathtaking church.



Church spire
This has had to be replaced on numerous occasions; one spire was destroyed during the French Revolution.

Engineering breakthrough
The thin walls between each glass panel were able to support the considerable weight by directing it toward their base.

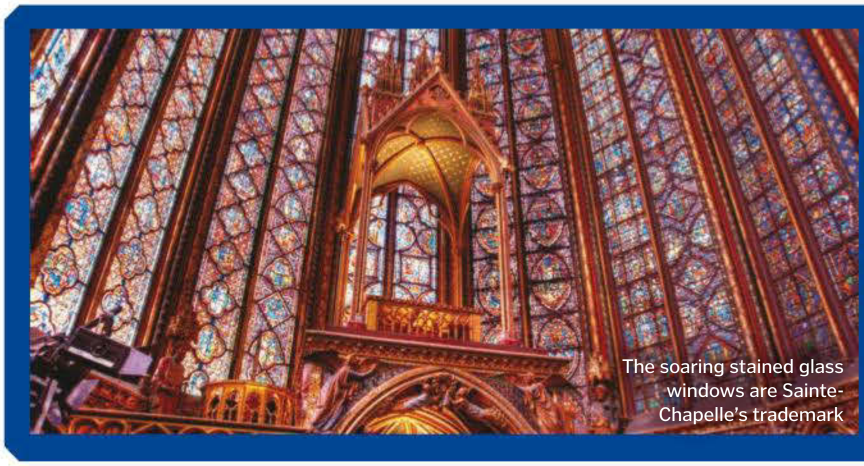
Stained glass
Each window group has four lancets, with three rose windows above them.

Rose window
The inclusion of this window is characteristic of Gothic architecture, seen in many cathedrals of this age in northern France.

Stained glass preservation
Recently, an innovative layer of protective glass has been applied to many of the stained glass windows.

Lower chapel
This functioned as the parish church, serving everyone who resided in the royal palace.

Producing stained glass



The soaring stained glass windows are Sainte-Chapelle's trademark

Making stained glass to a high standard is much easier now than it would have been during the Sainte-Chapelle's construction in the 13th century. Throughout this period, glass factories were located in areas with a good supply of silica such as sand, an essential ingredient for the mix. The overall process was much the same then as it is today; first you mix the silica, potash and lime along with a metallic oxide, which provides the colour. This could be copper oxide, which can produce blue, green or ruby colours depending on the conditions. These ingredients are then heated in a furnace to around 1,371 degrees Celsius (2,500 degrees Fahrenheit), creating molten glass. This stage was problematic in medieval times, as creating this heat with the techniques available was a lengthy process and hard to maintain. The molten glass can then be rolled into thin sheets and left to cool before cutting to the desired size.

© DK Images

DID YOU KNOW? *Abu Simbel is the second most popular tourist attraction in Egypt. It even has its own airport*

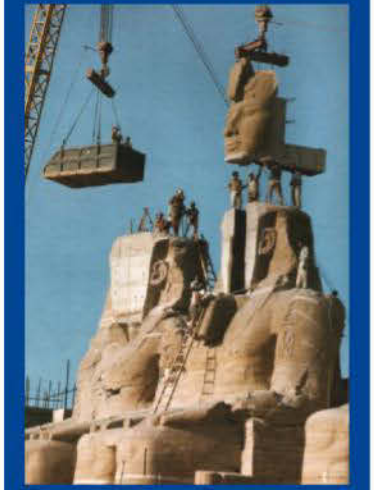
Abu Simbel

The incredible tale behind one pharaoh's tribute to himself

Egypt is no stranger to mind-blowing buildings and temples so it is a great compliment that the Abu Simbel rock temple at Nubia is one of the most visited sites in the country. Built during the reign of Ramesses II (circa 1279-1213 BCE), the construction of the two temples took 20 years to complete. The Great Temple is dedicated to the gods Ra-Horakty and Ptah, but it is Ramesses II that takes centre stage. The entrance to the temple is flanked by four 20-metre (65-foot) tall statues of Ramesses II that tower over the much smaller statues that depict the Pharoah's family as well as vanquished enemies such as the Nubians, Hittites and Libyans. Inside the Great Temple are statues of Ptah, Ra-Horakhty, Amun and Ramesses II as well as a number of reliefs that show Ramesses claiming great victories against his foes. A row of baboon statues line the façade as they were revered as Sun worshippers. The Little Temple was built to honour the memory of Ramesses' favourite wife Nefertari who later became known as the goddess of fertility and love. It is fronted by statues of Ramesses and Nefertari, while inside are reliefs that show the couple offering gifts to the gods. The location of Abu Simbel was very important as well. Nubia was already an important religious site and Abu Simbel, located at the Egyptian-Sudanese border, established it as definitively Egyptian.

Moving on up

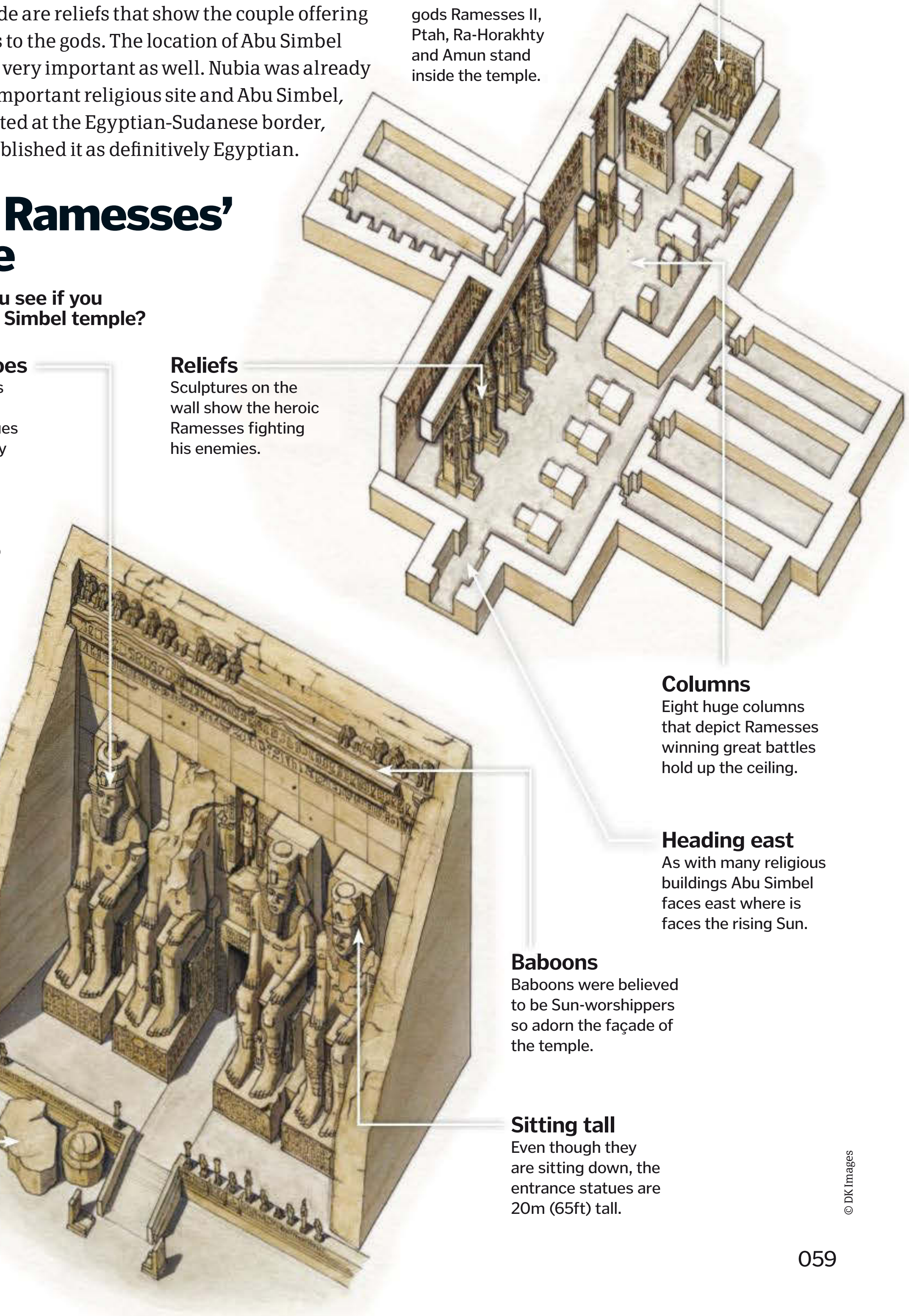
In 1952 the Egyptian Government made the decision to build a dam after the flood waters of the Nile got too high for the current one. However, this would have flooded the Abu Simbel temple so the decision was made to move the entire construction to higher ground. Between 1963 and 1968 the temple was cut into 10,000 blocks, each weighing between three and 20 tons. They were then moved 65 metres (213 feet) higher up the mountain and 180 metres (600 feet) to the west to keep it out of the soon-to-be-flooded area. The blocks were precisely re-assembled in exactly the same position as before and secured in place with concrete. The move cost $42 million at the time, which is around $288 million (£183 million) today, but was essential in preserving a key part of Egyptian history.



The task of moving the entire temple involved up to 3,000 people

Inside Ramesses' temple

What would you see if you visited the Abu Simbel temple?



Statues

The statues of the gods Ramesses II, Ptah, Ra-Horakhty and Amun stand inside the temple.

Friends and foes

In between the legs of the statues are much smaller statues of Ramesses' family and enemies.

Reliefs

Sculptures on the wall show the heroic Ramesses fighting his enemies.

Fallen idol

The head and torso of the second Ramesses statue lies on the ground having broken off following an earthquake.

Columns

Eight huge columns that depict Ramesses winning great battles hold up the ceiling.

Heading east

As with many religious buildings Abu Simbel faces east where is faces the rising Sun.

Baboons

Baboons were believed to be Sun-worshippers so adorn the façade of the temple.

Sitting tall

Even though they are sitting down, the entrance statues are 20m (65ft) tall.

© DK Images

Massachusetts State House

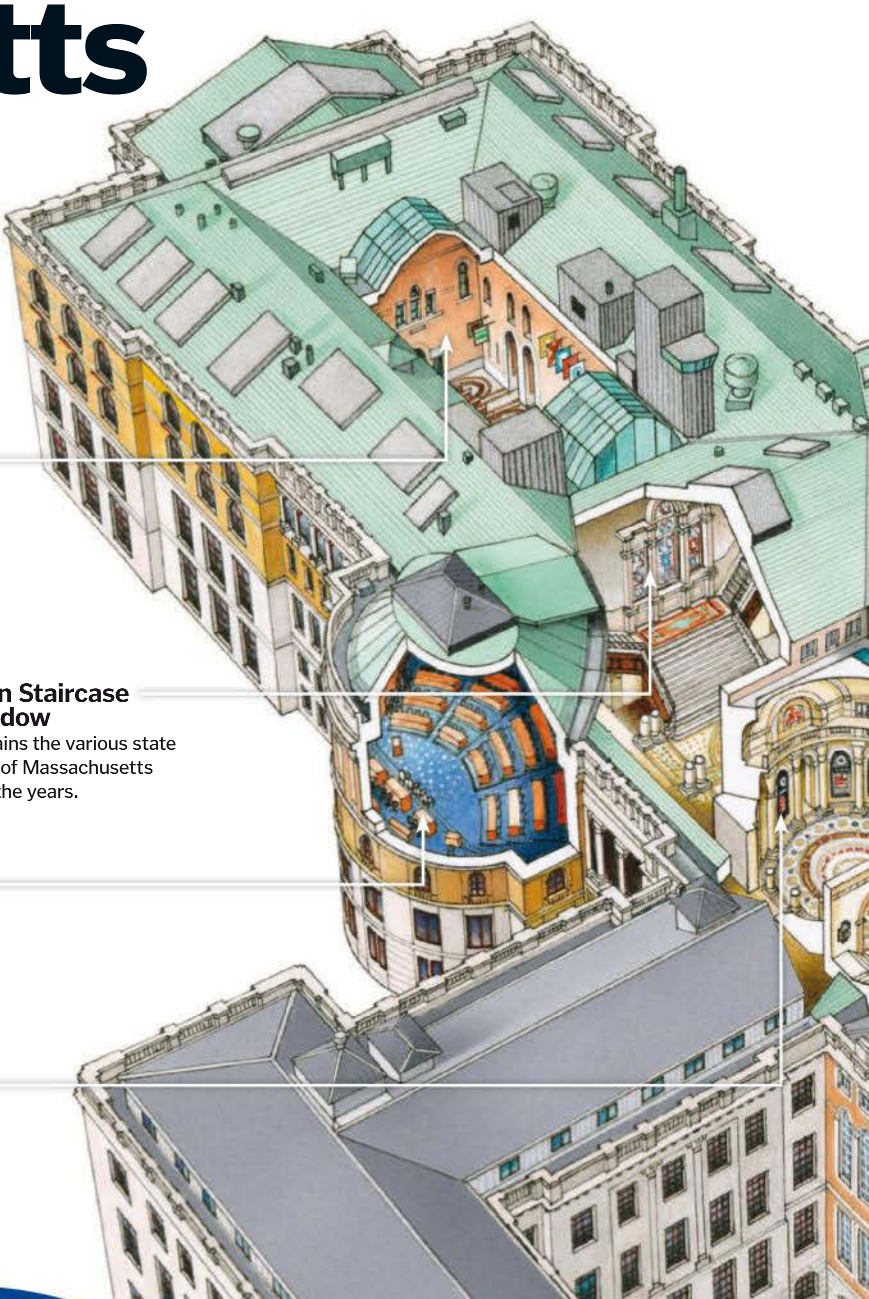
Why Boston's most iconic building has spades of symbolism to match its pomp

With the American Revolutionary War having ended in 1783, the still-young United States of America were striving to define their national identity. One of the ways in which the fledgling nation tried to achieve this was through the construction of grandiose and symbolic structures like Boston's capitol building, the Massachusetts State House.

The building was the brainchild of architect Charles Bulfinch, who took much of his inspiration from the two years he spent travelling around Europe. Construction commenced in 1795, with Patriots Samuel Adams and Paul Revere laying down its cornerstone in its location on top of Beacon Hill – a site once owned by John Hancock, the first elected governor of Massachusetts. Completed in 1798, it became an instant landmark, towering over the low-lying rest of the city and giving true credence to John Winthrop's epitaph of "a city on a hill."

The dome atop the State House is perhaps the section of its exterior that has changed the most over the years. Originally made of wood, it was overlaid with copper in the early-19th century before being covered in gold in 1874. During the Second World War it was painted dark for protection against the possibility of air raids during blackouts. The roof was finally re-gilded in 1997. On top of the dome itself is a wooden pine cone, symbolising the economic and cultural importance of the logging industry in the state's history.

Today, it still functions as the state's capitol building, hosting the Senate and House of Representatives' Chamber. Hanging up in the gallery in direct view of the Representatives is one of the most culturally significant sights in Boston: the Sacred Cod, which symbolises the importance of Boston's fishing industry to its prosperity. Combined with the numerous pieces of artwork and treasure in the building's confines, it's fair to say the building's history is extensive and far-reaching.



Great Hall
The newest addition to the building, construction was completed in 1990.

Main Staircase Window
Contains the various state seals of Massachusetts over the years.

House of Representatives
Home to the famous Cod, the chamber is situated on the third floor.

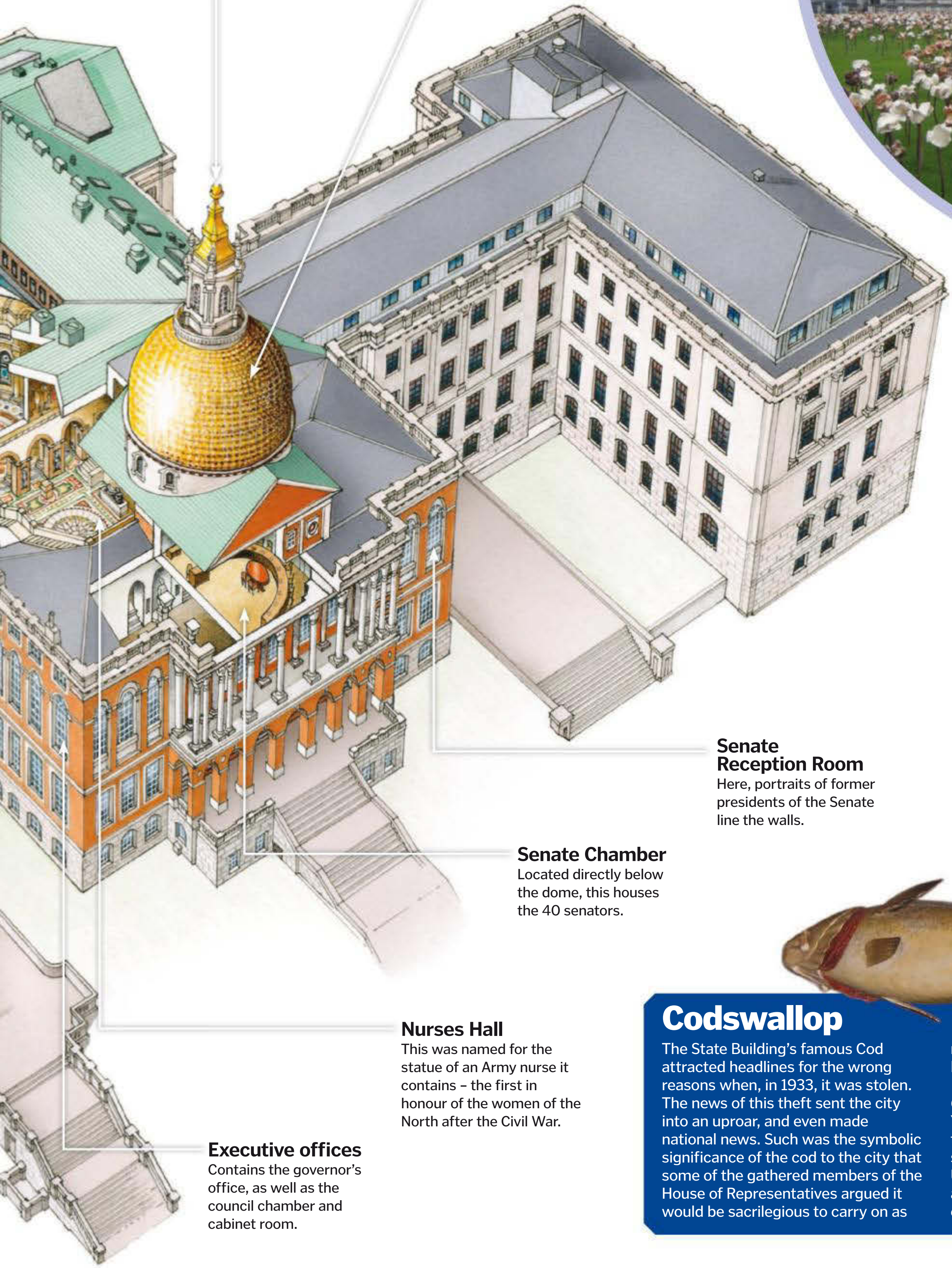
Hall of Flags
This room honours Massachusetts' soldiers and contains over 400 flags.

The Massachusetts State Library is as grand inside as out

DID YOU KNOW? *The Massachusetts State House can be seen in numerous scenes in Martin Scorsese's 2006 film The Departed*

Inside the State House

Your guide to the most important features of the Massachusetts State House



Pine cone
Located on top of the dome, this symbolises the importance of the logging industry to the city's history.

Dome
The dome was originally made out of wood, before being covered in copper and later gold.

Senate Reception Room
Here, portraits of former presidents of the Senate line the walls.

Senate Chamber
Located directly below the dome, this houses the 40 senators.

Nurses Hall
This was named for the statue of an Army nurse it contains – the first in honour of the women of the North after the Civil War.

Executive offices
Contains the governor's office, as well as the council chamber and cabinet room.

Inspirations for the State House's design

During his travels, Bulfinch drew on inspiration from a number of styles, which coalesced to form a building with a style of its own. One of the styles that can be most clearly observed in the building's design is Palladian in nature, drawing on the design themes present in the work of Italian architect Andrea Palladio (1508-80), notably the kind of symbolism seen in classical Greek architecture. A famous example of this can be seen in Somerset House, London (above), with the central part of the State House bearing the most obvious parallels with Palladian architecture.

In addition, Bulfinch's work evoked the neoclassical styles embodied by the likes of Scottish architect Robert Adam (1728-92), although in a move that evoked themes closer to home, wood was used for the columns in the colonnade, as well as for parts of the stairs and decorative bands on the columns.

Codswallop

The State Building's famous Cod attracted headlines for the wrong reasons when, in 1933, it was stolen. The news of this theft sent the city into an uproar, and even made national news. Such was the symbolic significance of the cod to the city that some of the gathered members of the House of Representatives argued it would be sacrilegious to carry on as normal without the famous fish looking over them.

The cod was eventually recovered (with only minor damage) by Harvard Yard police chief Charles Apted, with the cod-napping being blamed on the staff of *The Lampoon*, Harvard University's comedy magazine, although none if its members were ever charged.

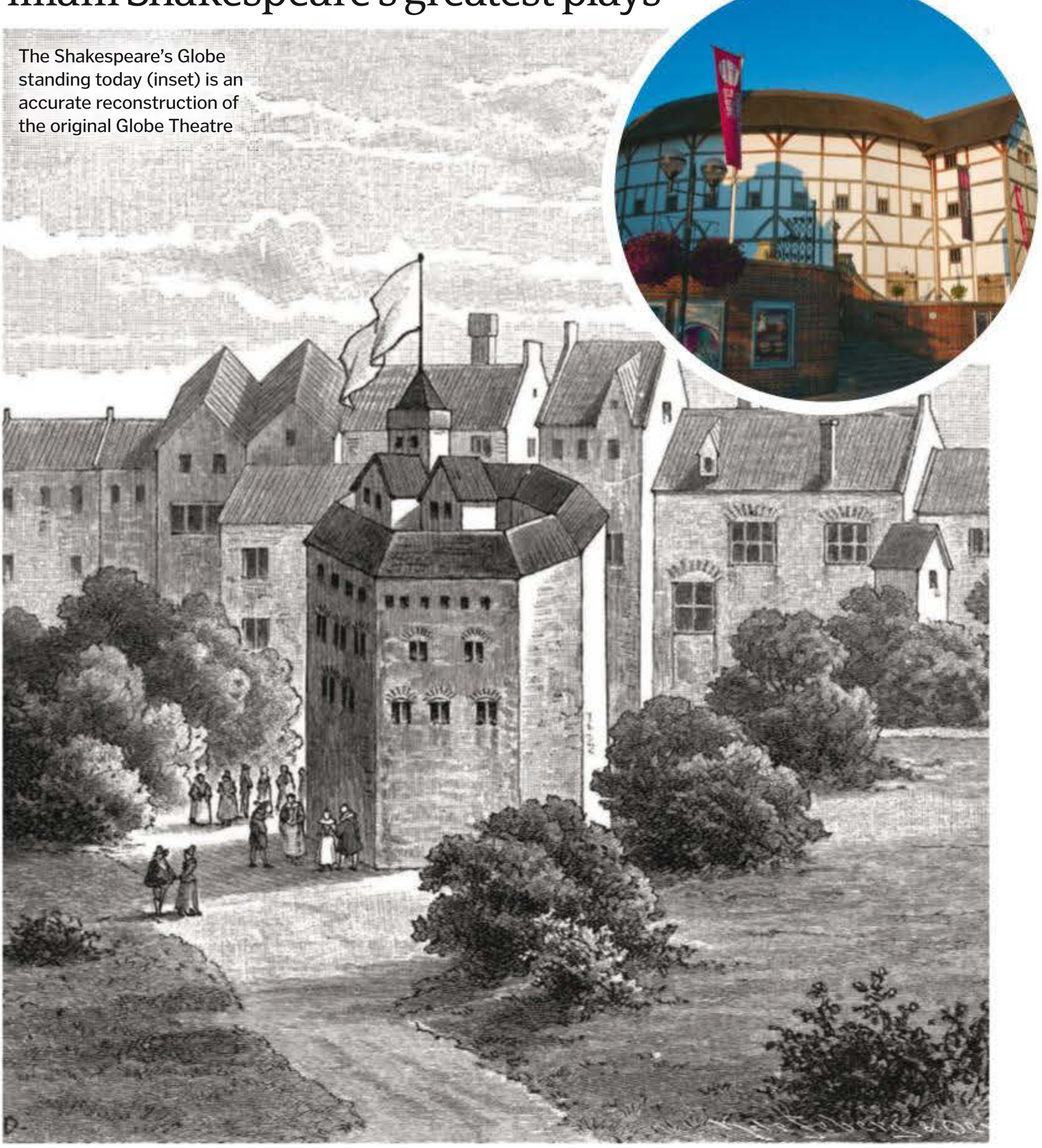
© Thinkstock

The Globe Theatre's story

The most famous and historic theatre in Britain – if not the world – the Globe was the original home to William Shakespeare's greatest plays

The Globe Theatre was an Elizabethan-era playhouse part-owned and made famous by the great playwright William Shakespeare. Built from the remains of an existing theatre in Shoreditch, London, made by English actor and theatre owner Richard Burbage and his brother Cuthbert, the Globe was constructed out of timber over just a few months in 1599. It was a very attractive and imposing theatre at its time. The playhouse became the home of the Lord Chamberlain's Men, a troupe of which Shakespeare and the Burbages were members. The group went on to perform many of the Bard's most famous plays there. Reportedly, the first performance was *Julius Caesar*, with subsequent famous plays such as *Richard II, Romeo And Juliet* and *A Winter's Tale* also shown there.

The Globe proved a great success, with its 3,000 capacity frequently tested to the limit, both in the cheap standing-only pit area as well as in the more prestigious tiered seating located around the inner walls. Unfortunately, however, on 29 June 1613 during a performance of *Henry VIII*, a theatrical cannon misfired and ignited the wooden beam and thatch roof, leading to the entire building burning down. Luckily, the success of the Globe's owners and its performances resulted in the theatre being rebuilt again in 1614, with the new playhouse continuing to host many acting troupes well after Shakespeare's death in 1616. In fact, it was not until 1642 that the theatre was closed down – a casualty of the English Civil War. Its legacy, however, is just as eternal as the plays written by the Bard himself.



The Shakespeare's Globe standing today (inset) is an accurate reconstruction of the original Globe Theatre

The Globe over time

Check out some of the main events in the theatre's history now

1599: Grand opening

The Globe Theatre is opened on Bankside, London.

1601: *Richard II* runs

Shakespeare's acting troupe, the Lord Chamberlain's Men, are commissioned to stage *Richard II*.

1608: Blackfriars bought

The Globe's co-owner, Richard Burbage, acquires the lease for the Blackfriars Theatre, which is then used for winter performances.

1614: Globe rebuilt

Following a disastrous fire that burned down the Globe, it is rebuilt a year later on the original foundations.

1616: Mortal coil

William Shakespeare dies aged 52 in Stratford-upon-Avon, where he is buried in the Holy Trinity Church.

1642: Plays suppressed

In the English Civil War, Parliament issues an ordinance that forbids all stage plays. The Globe is shut down.

1644: Globe destroyed

The theatre is razed to the ground again – this time by order of the Puritans. Landowner Sir Matthew Brend builds tenement houses on the site in its place.

1997: Resurrection

An accurate reconstruction of the Globe is built near to the site of the original building. It stages Shakespeare's works and is a popular tourist attraction to this day.

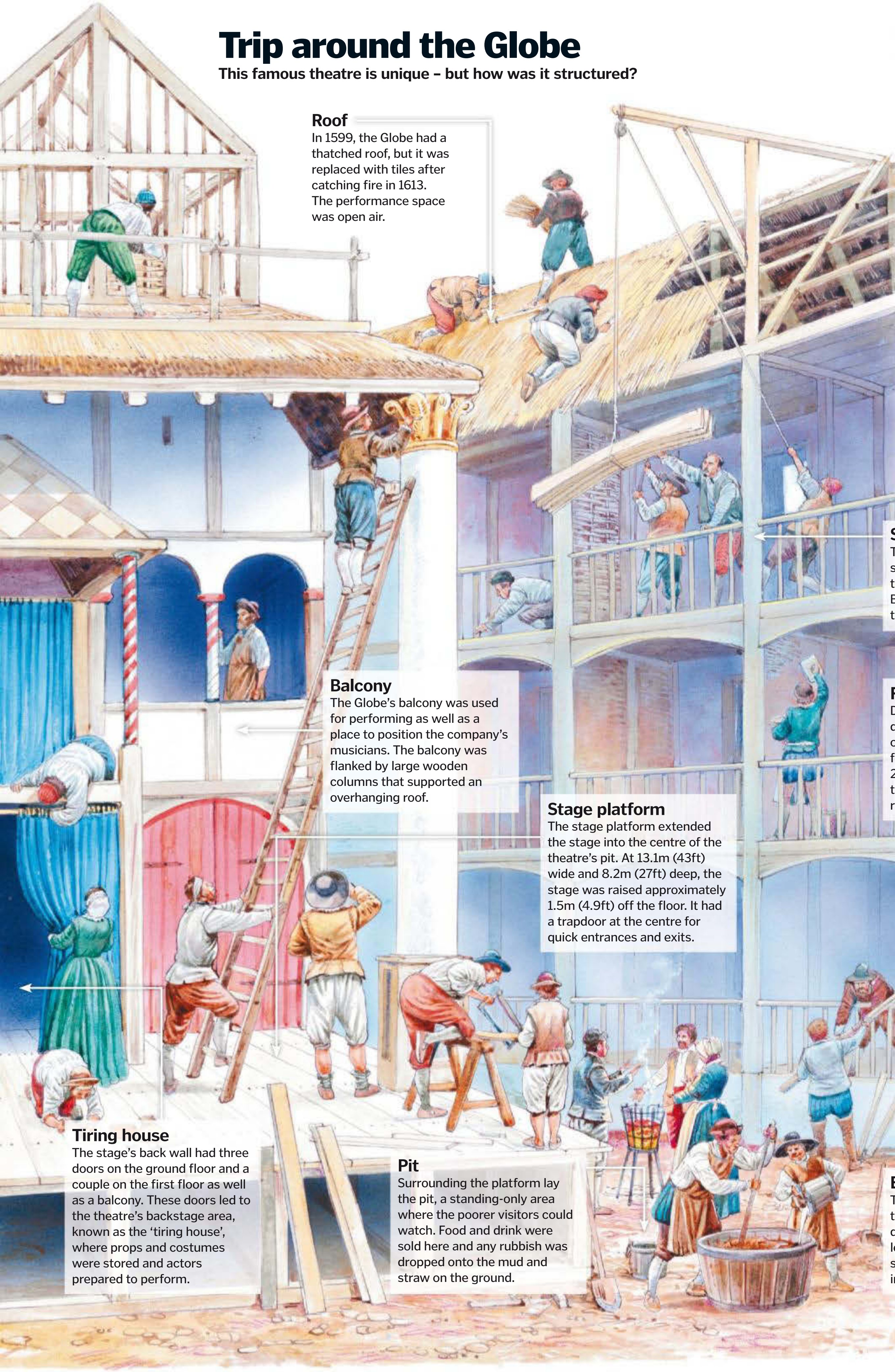
A modern-day Globe

Theatre fans today can visit the modern reconstruction of the Globe. It was nevertheless made to be historically accurate, consulting the plans, construction methods and materials of the 1599 original, albeit with modern safety standards in mind. Shakespeare's Globe is built from 100 per cent English oak, with components linked with mortise and tenon joints – both features shared by the original – and also has the only thatched roof permitted in all London since the Great Fire of 1666. The attention to historical detail even extends to the pit area, which remains standing only, albeit with a concrete surface rather than the earthen/straw mix of the 16th/17th century. A second Shakespearean play venue, the Blackfriars Theatre, has been reconstructed and opened as the Sam Wanamaker Playhouse in January 2014.

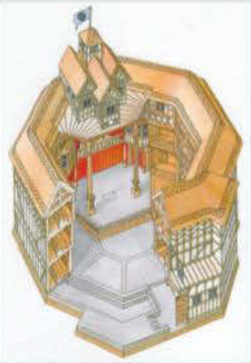
DID YOU KNOW? *The modern reconstruction of the Globe is located 230m (750ft) from the original site*

Trip around the Globe

This famous theatre is unique – but how was it structured?



The statistics…



Globe Theatre

Opened: 1599

Capacity: 3,000

Stage width: 13.1m (43ft)

Stage depth: 8.2m (27ft)

Theatre diameter: 30m (100ft)

Closed: 1642

Roof

In 1599, the Globe had a thatched roof, but it was replaced with tiles after catching fire in 1613. The performance space was open air.

Balcony

The Globe's balcony was used for performing as well as a place to position the company's musicians. The balcony was flanked by large wooden columns that supported an overhanging roof.

Storeys

The Globe had a three-storey seating arrangement used by the middle and upper classes. Basically the higher the seat, the more expensive it was.

Stage platform

The stage platform extended the stage into the centre of the theatre's pit. At 13.1m (43ft) wide and 8.2m (27ft) deep, the stage was raised approximately 1.5m (4.9ft) off the floor. It had a trapdoor at the centre for quick entrances and exits.

Foundations

Despite appearing circular in design, with a diameter of just over 30m (98ft), the Globe's foundations were actually a 20-sided polygon (icosagon). At the centre of the theatre lay the rectangular stage platform.

Tiring house

The stage's back wall had three doors on the ground floor and a couple on the first floor as well as a balcony. These doors led to the theatre's backstage area, known as the 'tiring house', where props and costumes were stored and actors prepared to perform.

Pit

Surrounding the platform lay the pit, a standing-only area where the poorer visitors could watch. Food and drink were sold here and any rubbish was dropped onto the mud and straw on the ground.

Entrance (not shown)

There was one main entrance to the theatre, which was directly opposite the stage and led into the pit. Two sets of stairs near the entrance led into the upper seating tiers.

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Brooklyn Bridge

One of New York's most recognisable landmarks, the Brooklyn Bridge was the first-ever steel-wire suspension bridge

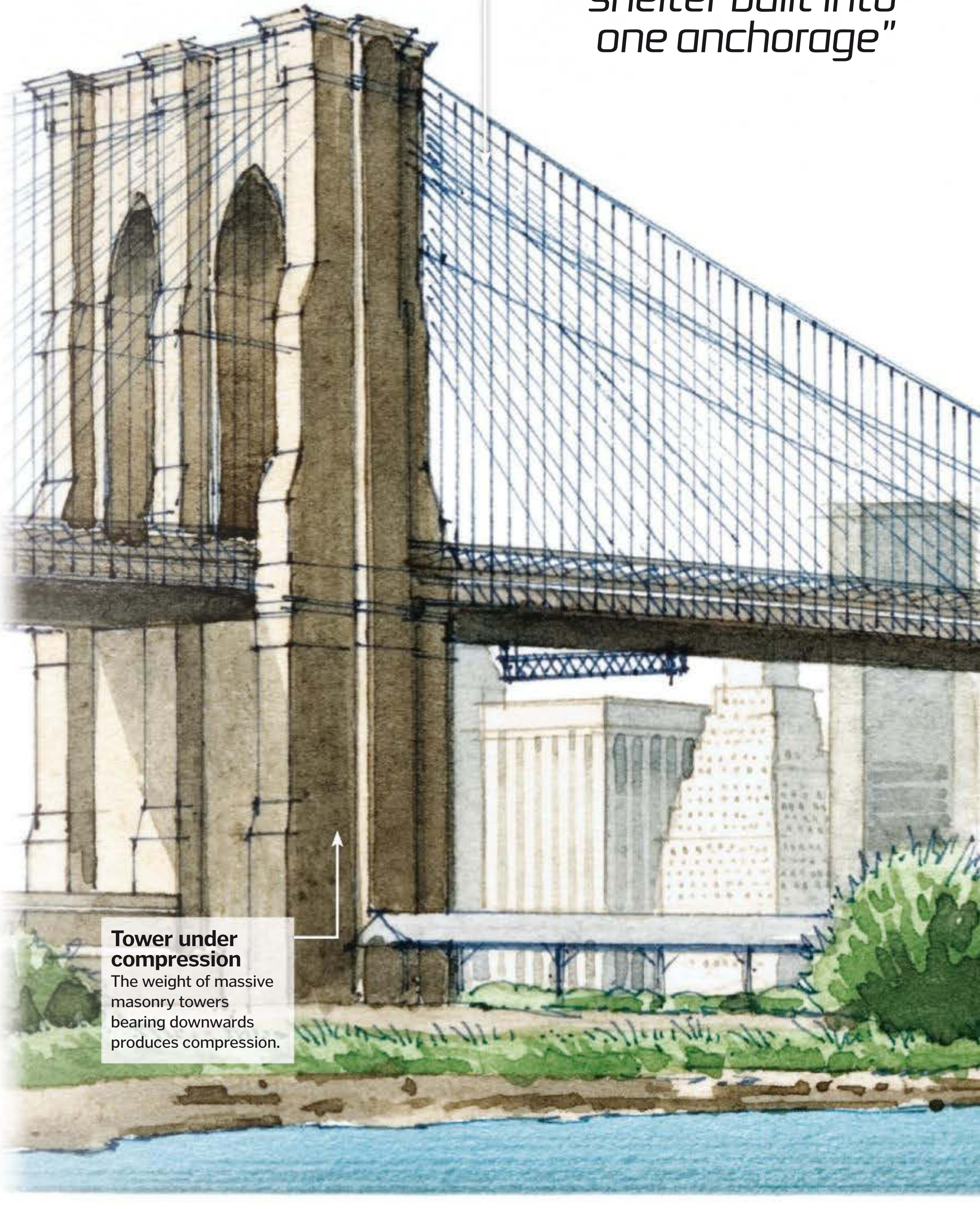
Built between 1870 and 1883, the Brooklyn Bridge links Brooklyn and Manhattan by spanning the East River in New York City. Designed by a German immigrant, John Augustus Roebling, it was his son, Washington Roebling, and daughter-in-law, Emily, who actually oversaw most of the construction after John's unexpected death just months before building commenced.

The bridge consists of two main elements. Firstly, there are the two anchorages that are positioned either side of the river and between them are two towers (also known as piers) which stand at approximately 84 metres (277 feet) high. Consisting of limestone, granite and cement, the towers – designed in a neo-Gothic architectural style – stand on concrete foundations that run 13.4 metres (44 feet) and 23.8 metres (78 feet) deep on the Brooklyn and Manhattan sides, respectively.

Secondly, the bridge itself is constructed from iron and steel-wire cables, with a layer of tarmac on the main deck. At 26 metres (85 feet) wide and 1,825 metres (5,989 feet) long, the Brooklyn Bridge was the longest suspension bridge in the world when first built and held the record for over 20 years. Roebling's design includes many redundancies, such as a diagonal stay system between cables and stiffening trusses, which make the bridge very safe; indeed, even if one of the main support systems were to fail altogether the bridge would sag, rather than completely collapse.

More unusually, the bridge also has its own nuclear fall-out shelter built into one anchorage. Having fallen out of use and been forgotten, the shelter was rediscovered in 2006, along with provisions from the Cold War era. Designated a National Historic Landmark in 1964, since the Eighties the bridge has been floodlit at night to highlight its distinct architectural features. Initially intended to carry motor vehicles, trains, street cars, bicycles and pedestrians, since the Fifties, the bridge has only taken cars, cyclists and foot traffic. Over 120,000 vehicles, 4,000 pedestrians and 3,100 cyclists cross it every day.

> *"More unusually, the bridge also has its own nuclear fall-out shelter built into one anchorage"*



Suspenders under tension
The two opposing forces – the cables and the bridge deck – in balance produce tension in the suspenders.

Tower under compression
The weight of massive masonry towers bearing downwards produces compression.

DID YOU KNOW? *In 1884, showman PT Barnum paraded 21 elephants over the Brooklyn Bridge, proving its stability*

The origins of suspension bridges

In a suspension bridge the deck – the load-bearing portion – is hung below suspension cables on vertical suspenders which bear the weight. Although bridges of this design first seem to have been invented in 15th-century Tibet, it was really the 19th century which saw their application on a massive scale.

The materials used in the construction of the Brooklyn Bridge were sourced in the US. The granite blocks were quarried in Maine and delivered to New York by boat. The wire rope and steel cable were produced in local factories, while the pigment used in the red paint with which the bridge was originally covered came from the mines at Rawlins, Wyoming.

The design and construction techniques employed in the Brooklyn Bridge have changed little in their essentials over the last century or so. Although at least 81 suspension bridges today are longer than the Brooklyn Bridge, they are all fundamentally the same – except that now the materials tend to be drawn from all over the globe rather than sourced locally.

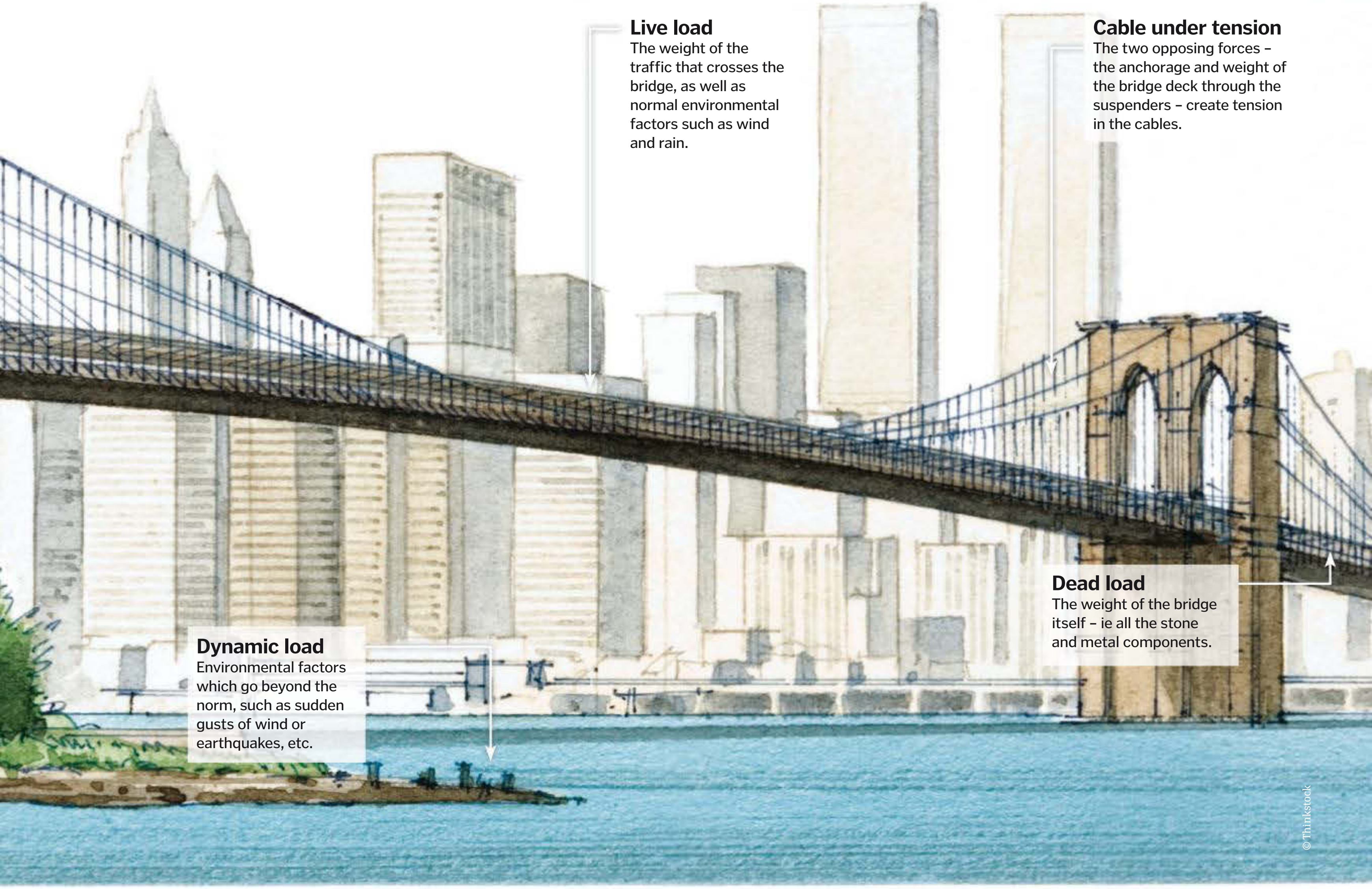
The Brooklyn Bridge during construction in the late-19th century

Cultural impact

Since its completion, the Brooklyn Bridge has inspired many an artist and poet. The modernist American poet Hart Crane, for example, famously published the ode *To Brooklyn Bridge* in 1930. Regarded as a wonder of its age, people flocked to see the structure's opening with a spectacular fireworks display and regatta in 1883 – a celebration which was repeated on its 100th anniversary.

Many people have jumped off the bridge as publicity stunts or suicide attempts, while others have got married on it. In 1919 the Caproni heavy bomber, which was then the world's largest aeroplane, was flown under the deck, while in 2003 it was the intended target of an Al-Qaeda terrorist plot.

The Brooklyn Bridge has also frequently appeared in Hollywood movies, such as *I Am Legend*, *The Dark Knight Rises, Godzilla*, and more recently *The Amazing Spider-Man 2.*



Live load
The weight of the traffic that crosses the bridge, as well as normal environmental factors such as wind and rain.

Cable under tension
The two opposing forces – the anchorage and weight of the bridge deck through the suspenders – create tension in the cables.

Dead load
The weight of the bridge itself – ie all the stone and metal components.

Dynamic load
Environmental factors which go beyond the norm, such as sudden gusts of wind or earthquakes, etc.

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What went wrong at Chernobyl?

Learn how a runaway reaction led to a nuclear disaster…

On 25 April 1986, engineers at the nuclear plant at Chernobyl began a test that would lead to the worst nuclear disaster in history. The power plant, located some 130 kilometres (80 miles) north of Kiev, Ukraine, was completed in 1983. Three years later, engineers ran an experiment to see how long the turbines could continue producing energy in the event of a power cut.

The first fatal error made by the technicians that day was to turn off the crucial safety systems in the facility. They would have affected the experiment, which involved running the plant at low power, but this action prevented workers realising the dire situation they were soon to put themselves in.

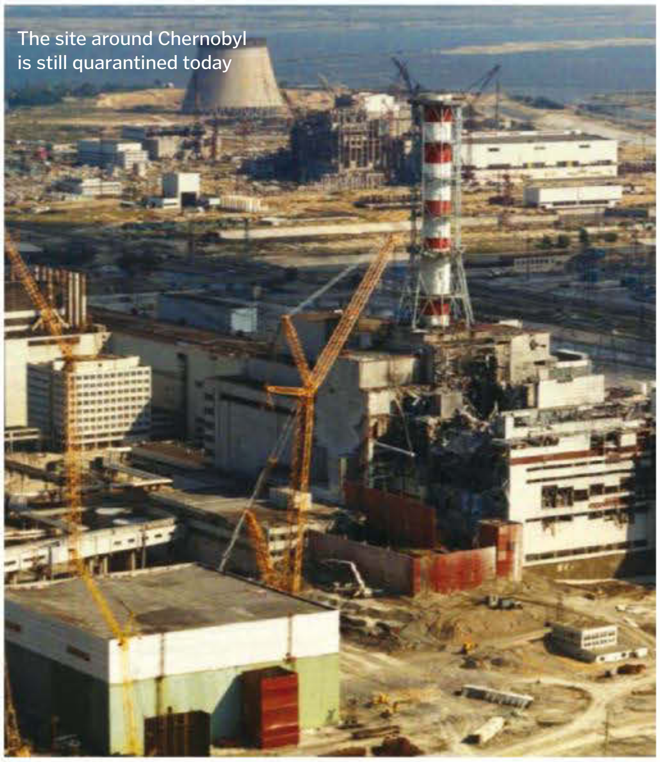
The process of creating nuclear fission is regulated by control rods, which, when inserted into the reactor core, absorb neutrons and slow production. The idea was to lower lots of these rods to reduce the power output and see what happened. Unfortunately, too many were lowered and the output dropped at too high a rate. Rods were then raised again to increase output, returning to about 12 per cent.

However, due to the rods being raised too far and too quickly, a dangerous power surge occurred and the reactor overheated, the water cooling system unable to cope with the sudden demand, turned to steam.

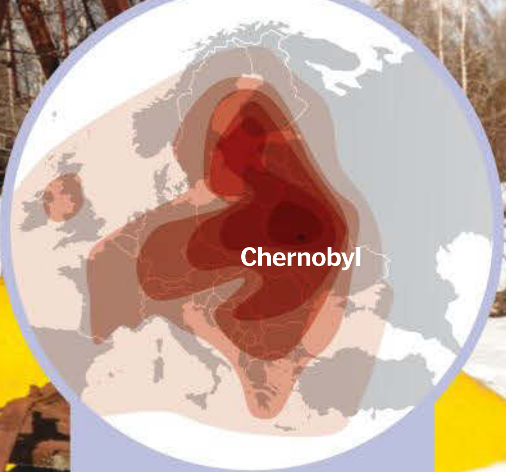
The emergency button was pressed and the rods began to lower but this led to even more rapid reactions in the core.

In the early hours of 26 April, the reactor's roof was blown off and radioactive material began to escape into the atmosphere.

The fire took nine days to extinguish and the radioactive material had far-reaching health and political consequences.



The site around Chernobyl is still quarantined today



Nuclear fallout

The explosion and meltdown was shocking enough, but worse was still to come in the form of radiation spread and health issues for much of Europe.

31 people died immediately after the event with 28 of those deaths a direct result of radiation poisoning inside and around the power plant site.

The worst of the fallout centred around Chernobyl, but increased levels of radiation were detected in areas as far away as the UK, Portugal and Sweden.

Thyroid cancer, caused by the inhalation of contaminated air, has increased tenfold in adolescents in Belarus since 1986 with cases in adults also rising. Cases in children up to the age of 14 also increased, but that number has since reduced due to many of that age group being born after the event.

The impact of the contaminated air has also affected animals, crops and water supplies and the effects are still widely felt to this day. Radiation levels around Chernobyl will remain far higher than average for many millennia.

DID YOU KNOW? *At least 30 of the 50 rods needed to be inserted to be safe; when the plant exploded only six were inserted*

Countdown to disaster

Find out how history's worst nuclear accident played out

① Safety switches
The safety switches were intentionally turned off to allow the experiment to run without intervention

② Rods dropped
Control rods were lowered to reduce power output, but the power reduced too much too quickly.

③ Rods raised
In order to get the plant working again, the rods were raised causing a rapid increase in production.

④ Water heating
The all-important cooling water began to overheat, turning to steam and failing to cool the reactor.

⑤ Emergency
Pressing the emergency button lowered the rods again, but they displaced the remaining water.

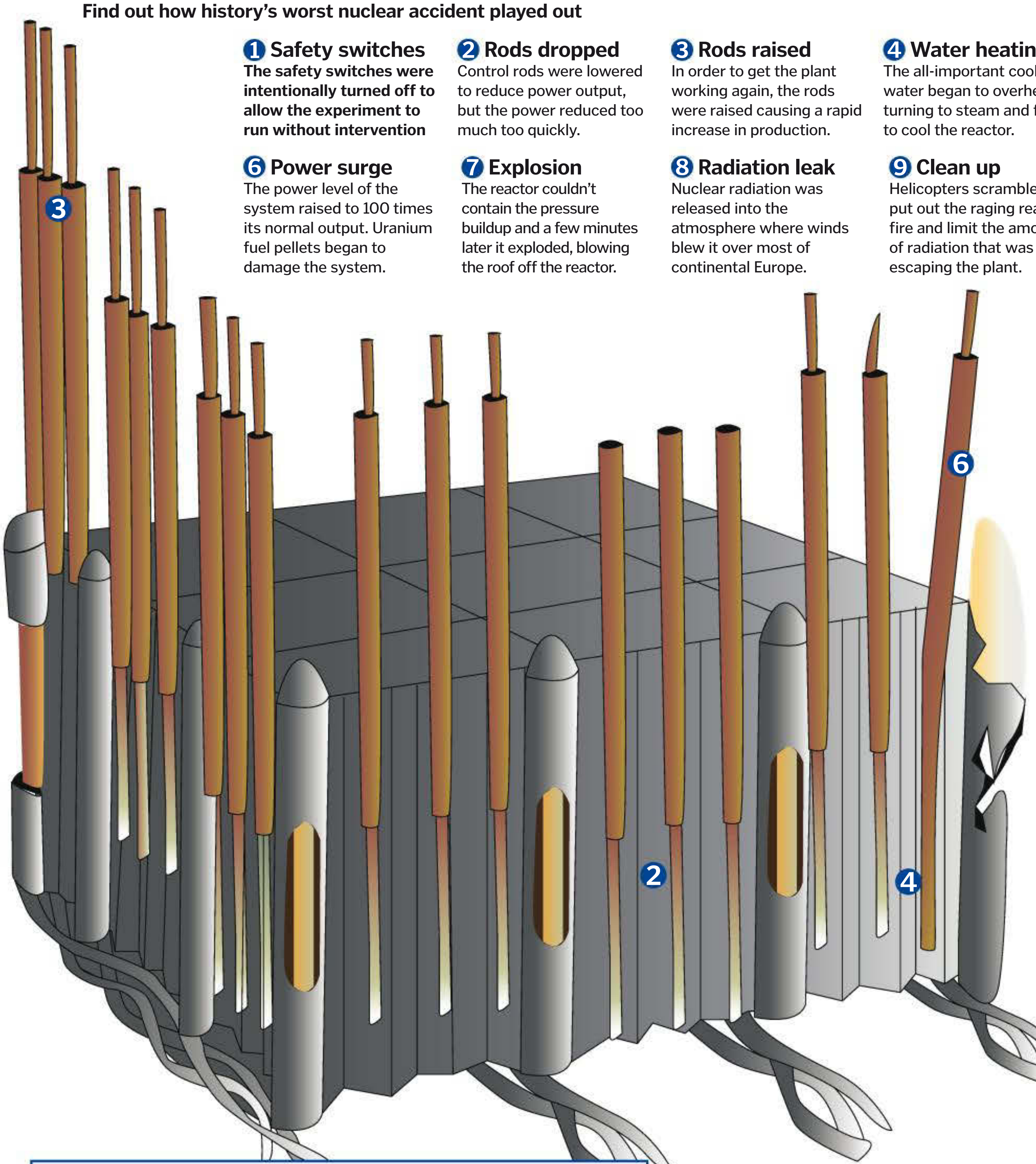
⑥ Power surge
The power level of the system raised to 100 times its normal output. Uranium fuel pellets began to damage the system.

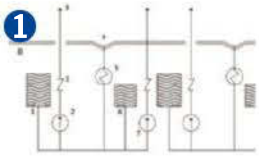
⑦ Explosion
The reactor couldn't contain the pressure buildup and a few minutes later it exploded, blowing the roof off the reactor.

⑧ Radiation leak
Nuclear radiation was released into the atmosphere where winds blew it over most of continental Europe.

⑨ Clean up
Helicopters scrambled to put out the raging reactor fire and limit the amount of radiation that was escaping the plant.

⑩ Sarcophagus
A concrete shell was hastily constructed and placed over the nuclear plant to limit the release of radiation from Chernobyl.





How it toppled the USSR

The leader of the Soviet Union at the time of the Chernobyl disaster, Mikhail Gorbachev, has claimed that the incident was a key factor in the demise of the USSR.

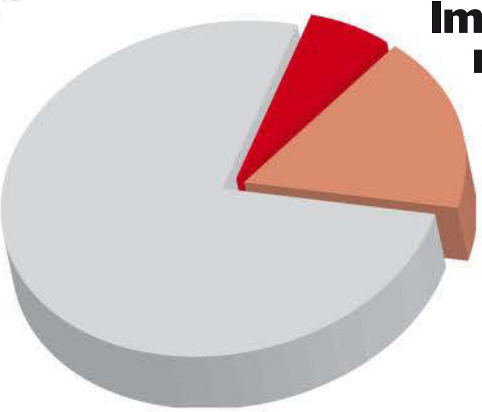
The government's response to the disaster was to try and cover it up as much as possible, with barely any official announcement of it and no warning to residents in the surrounding area as to the dangers of radioactive poisoning. It took a radioactive cloud that passed over Sweden to bring the event to the world's attention.

Furious at the lack of information and protection they had received, especially as Gorbachev had promised a new era of political clarity and honesty, citizens railed against the political system.

The general public lost faith in the government and the government in turn lost control of the general public. Five years later, the Soviet Union was dissolved with Gorbachev quoted as saying, "The nuclear meltdown at Chernobyl […] was perhaps the real cause of the collapse of the Soviet Union."

Impact of the meltdown

How many were directly affected by the disaster?



🟥 **55,000** 6.4% died from radiation

🟧 **150,000** 17.4% were left disabled

⬜ **655,000** 76.2% underwent medical supervision

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Why has trench warfare come to define WWI?

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Discover the true story behind history's infamous bloodthirsty buccaneers

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Step into the aircraft that trained pilots for WWII

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How did this incredible war machine revolutionise aerial warfare?

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The key mechanisms of these fold-up entrances

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How does a whip break the sound barrier?

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How were these powerful siege engines built and used?

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What made the Zulu warriors so successful?

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The origins of this popular military unit

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The most famous conflict of the Hundred Years' War

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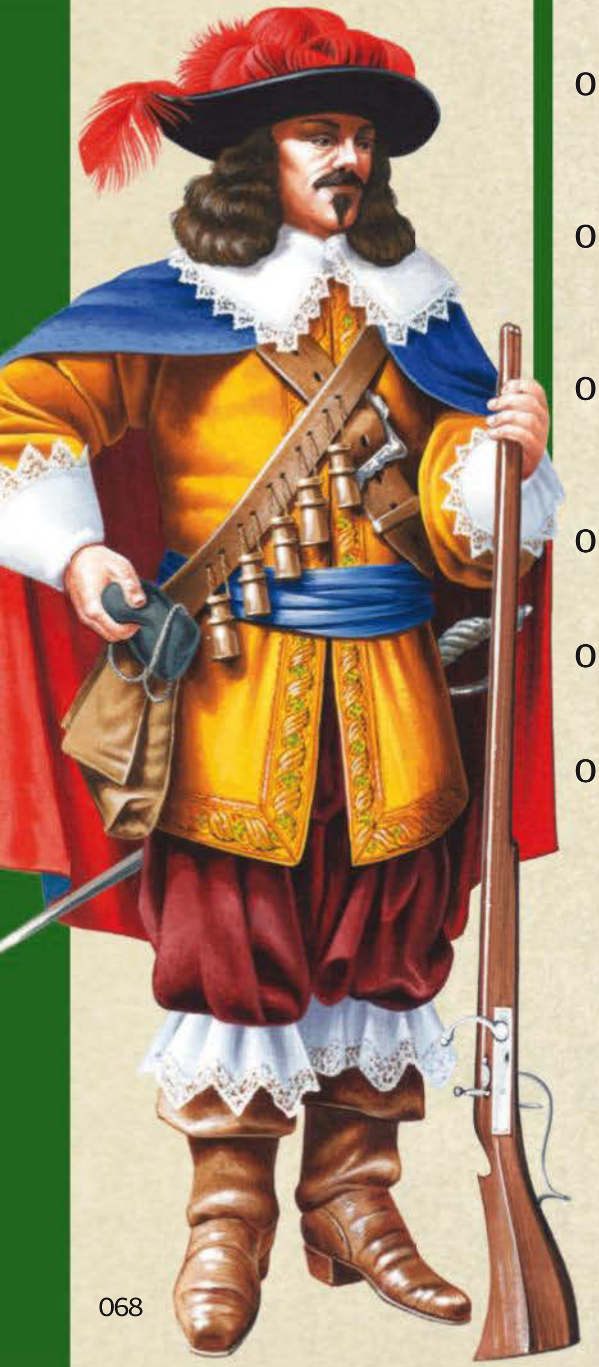
The intricacies of this glamorous martial sport of the Middle Ages



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Meet the musketeers

Flying a WWII plane
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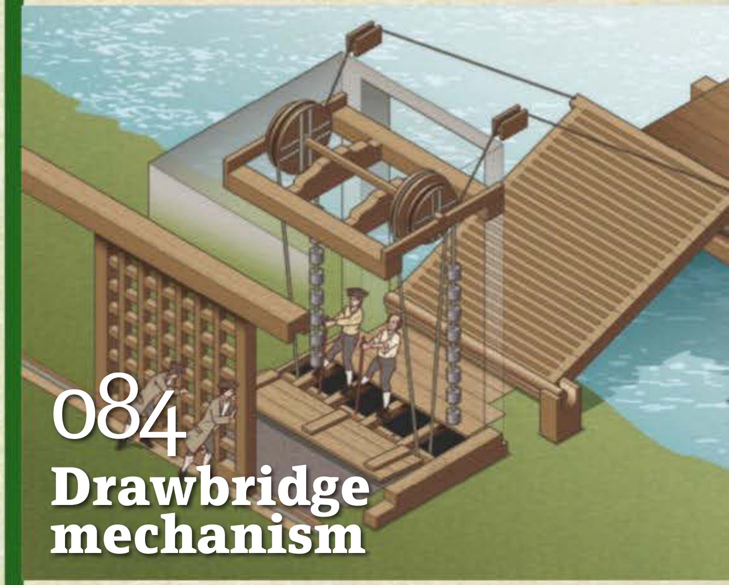

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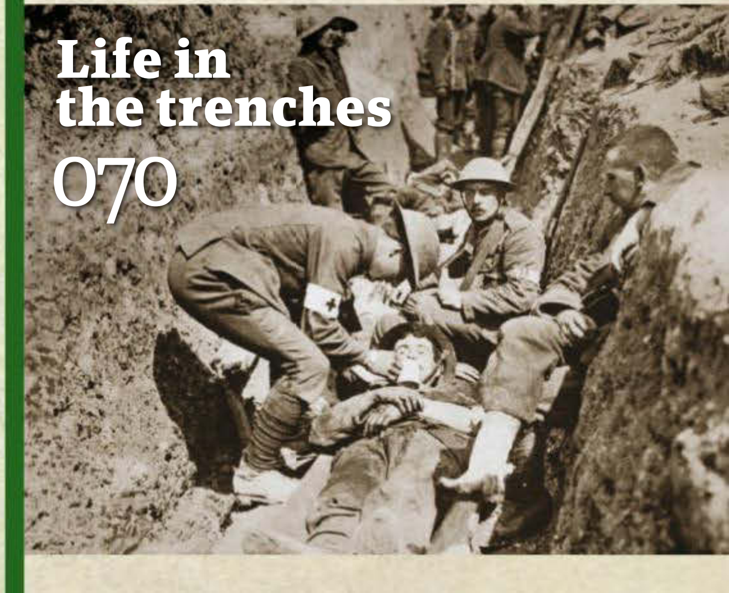
Drawbridge mechanism



Life in the trenches
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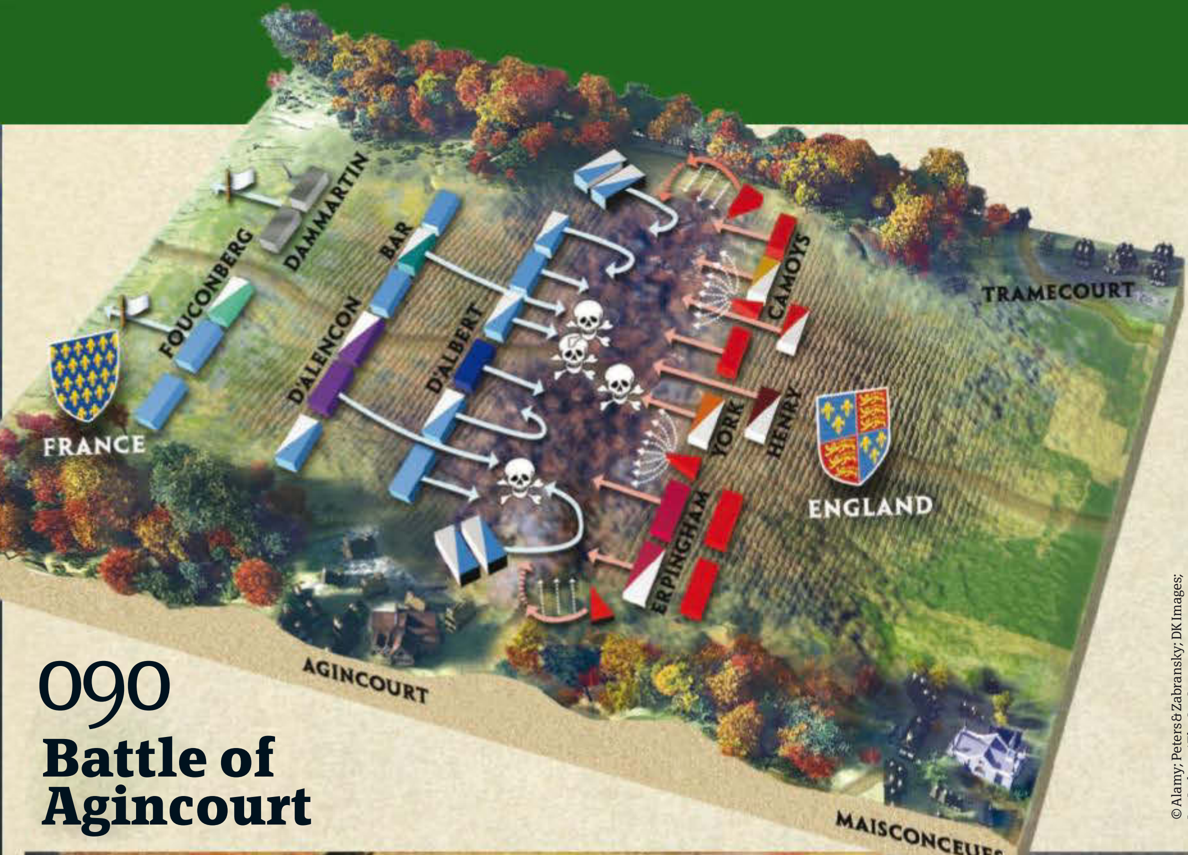
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TRAMECOURT
AGINCOURT
MAISCONCEUES

090
Battle of Agincourt

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Cut-throat Pirates
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Jousting armour

MH-60Black Hawk
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Life in the trenches

Why has trench warfare come to define WWI?

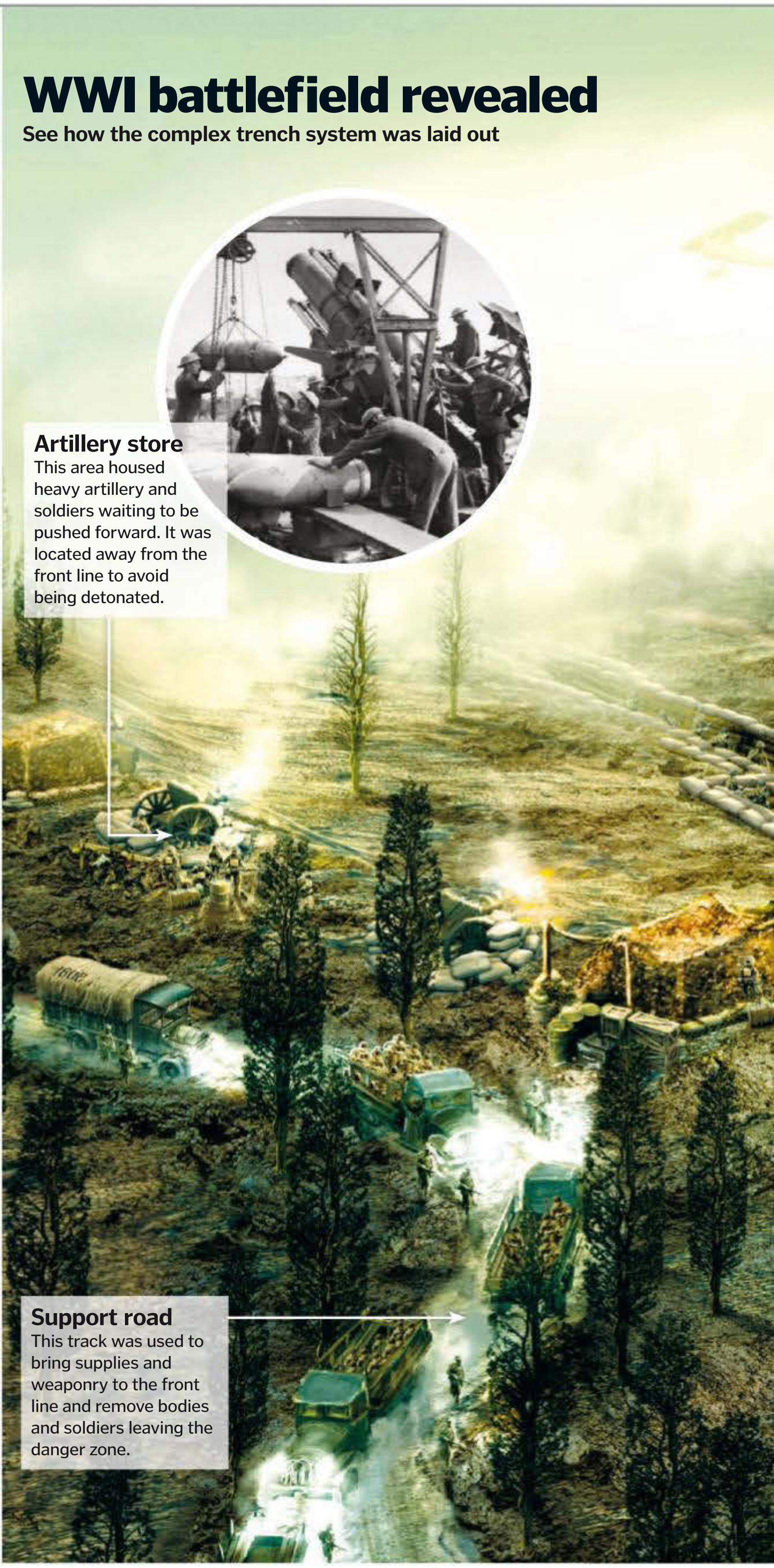
World War I represented a major shift in warfare practice. Aircraft and machine guns were two examples, but what truly dictated this conflict was trench warfare.

The first trenches of note were dug by Germans in September 1914 after their charge through France was halted by Allied forces. In order to avoid losing ground, they dug in, creating deep crevasses to hide in. The Allies quickly realised they couldn't breach these defences and followed suit. What ensued was a race to outflank the opponent along northern France. The first trenches were fairly shallow ditches, but evolved into an elaborate system of frontline trenches, support trenches and barbed wire fences.

It would take 450 men six hours to construct a trench of just 250 metres (820 feet), after which sandbags, wooden walkway planks and barbed wire needed to be strategically placed to stop flooding, collapsing and enemy advances. They were dug in zigzag patterns to stop enemies taking out an entire group of soldiers in one attack. The most time-effective method of trench digging was standing on the ground and digging downward, but that left soldiers at the mercy of enemy fire. The alternative was to dig down then along, while still in the hole. This was safer but much slower.

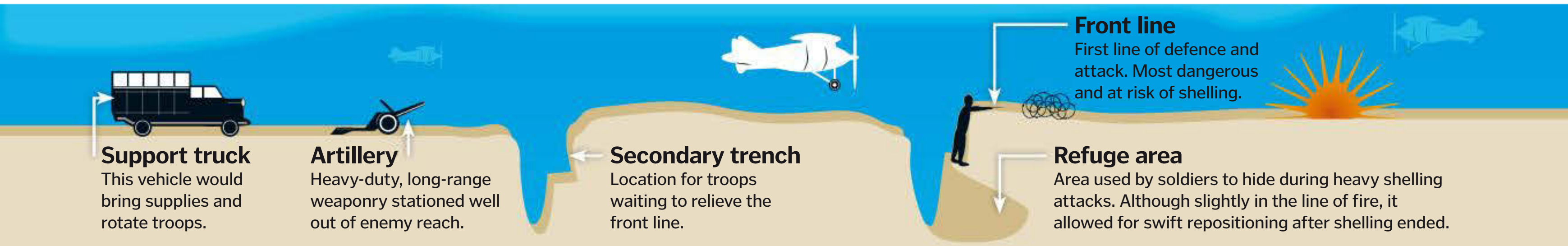
WWI battlefield revealed

See how the complex trench system was laid out



Artillery store
This area housed heavy artillery and soldiers waiting to be pushed forward. It was located away from the front line to avoid being detonated.

Support road
This track was used to bring supplies and weaponry to the front line and remove bodies and soldiers leaving the danger zone.



Support truck
This vehicle would bring supplies and rotate troops.

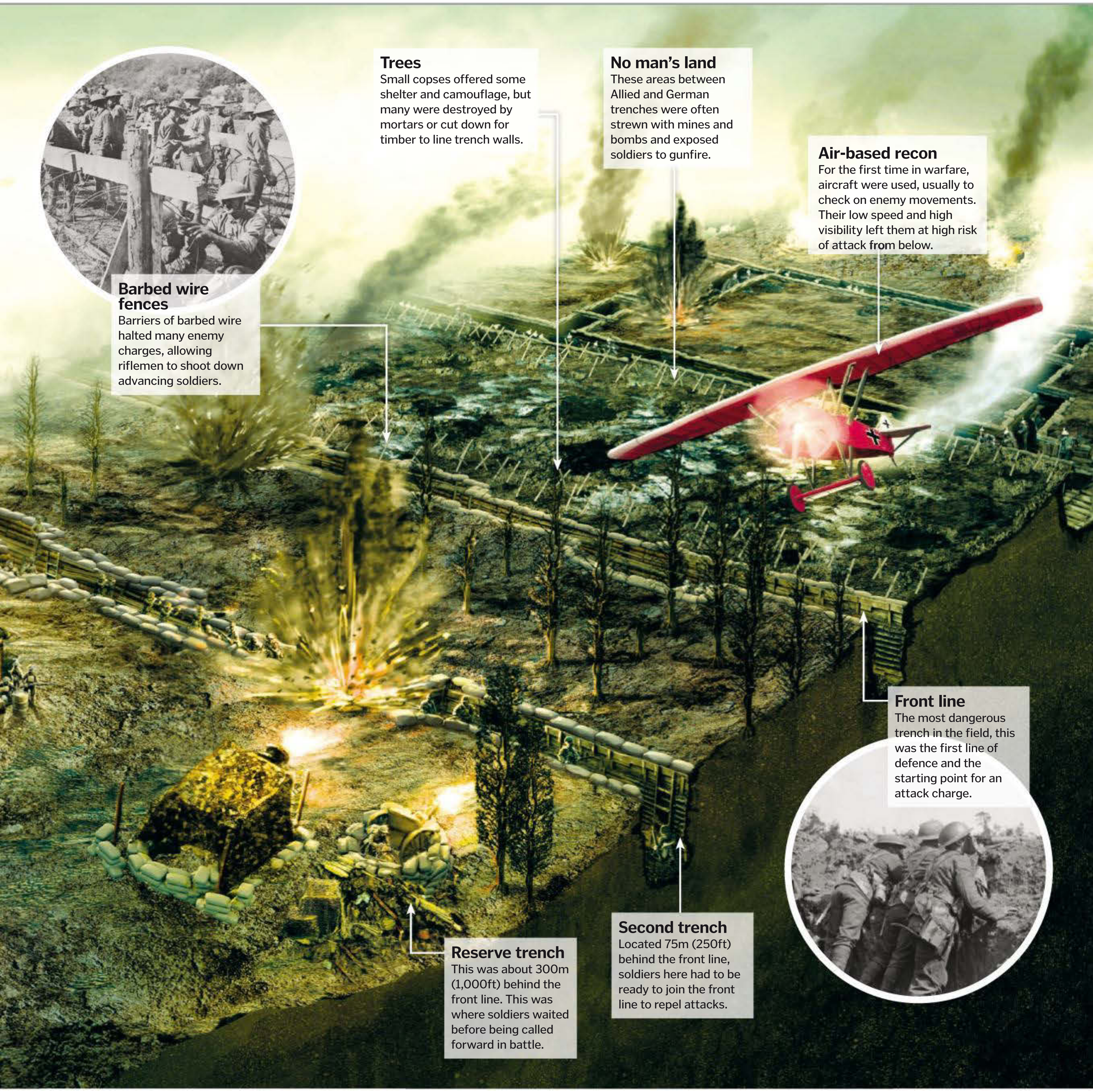
Artillery
Heavy-duty, long-range weaponry stationed well out of enemy reach.

Secondary trench
Location for troops waiting to relieve the front line.

Front line
First line of defence and attack. Most dangerous and at risk of shelling.

Refuge area
Area used by soldiers to hide during heavy shelling attacks. Although slightly in the line of fire, it allowed for swift repositioning after shelling ended.

DID YOU KNOW? *Around 140,000 Chinese labourers fought in Allied trenches during World War I*



Trees
Small copses offered some shelter and camouflage, but many were destroyed by mortars or cut down for timber to line trench walls.

No man's land
These areas between Allied and German trenches were often strewn with mines and bombs and exposed soldiers to gunfire.

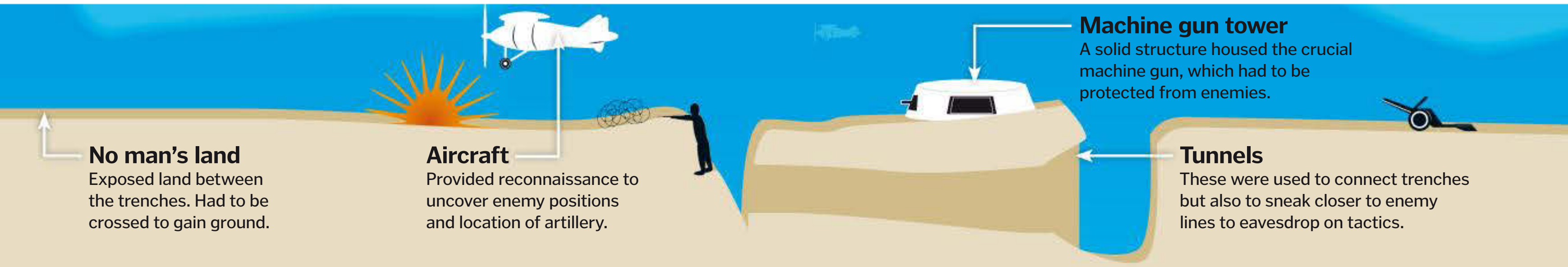
Air-based recon
For the first time in warfare, aircraft were used, usually to check on enemy movements. Their low speed and high visibility left them at high risk of attack from below.

Barbed wire fences
Barriers of barbed wire halted many enemy charges, allowing riflemen to shoot down advancing soldiers.

Front line
The most dangerous trench in the field, this was the first line of defence and the starting point for an attack charge.

Reserve trench
This was about 300m (1,000ft) behind the front line. This was where soldiers waited before being called forward in battle.

Second trench
Located 75m (250ft) behind the front line, soldiers here had to be ready to join the front line to repel attacks.



Machine gun tower
A solid structure housed the crucial machine gun, which had to be protected from enemies.

No man's land
Exposed land between the trenches. Had to be crossed to gain ground.

Aircraft
Provided reconnaissance to uncover enemy positions and location of artillery.

Tunnels
These were used to connect trenches but also to sneak closer to enemy lines to eavesdrop on tactics.

Located in north-east France, Marne was the site of the war's first example of trench warfare. German and Allied forces both realised the defensive power of this strategy so engaged in a shovelling 'Race to the Sea', building trenches all the way to the North Sea at Ypres, Belgium.

This then became the location for a bed-in that lasted for the remainder of the war, with attacks and counterattacks barely gaining any ground at all, but at the cost of millions of lives.

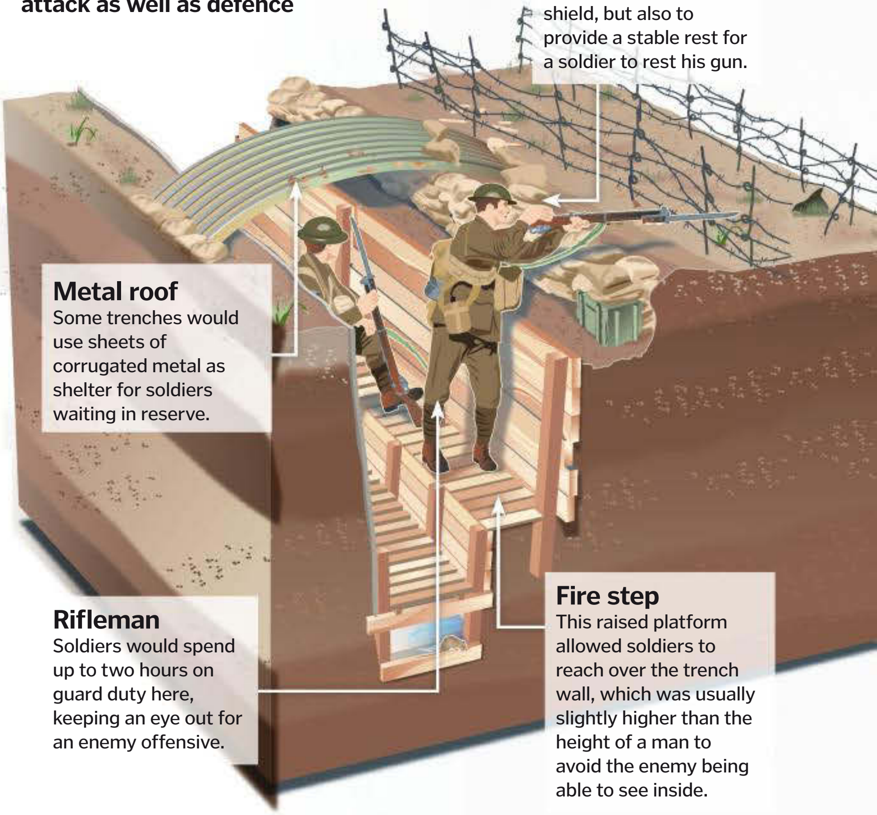
Verdun was another bloody site, with the Germans launching a devastating attack on the fortified town. They broke French resistance but the counter-offensive eventually drove them back to their starting point, resulting in a similarly prolonged trench standoff.

The German forces failed to conquer Verdun because they had to focus on the British army's assault on the Somme. This began with a massive week-long bombardment followed by an infantry attack. However, the German trenches were so well fortified that the British shells barely made an impact, so thousands of Allied troops fell victim to the ruthless German machine guns.

The end came at St Quentin Canal in France. The British managed to storm through the Hindenburg Line, forcing the Germans back and bringing about the first discussions of surrender.

Trench firepower

Trenches served as a point of attack as well as defence



Barrier
Sandbags were put here partly to act as a shield, but also to provide a stable rest for a soldier to rest his gun.

Metal roof
Some trenches would use sheets of corrugated metal as shelter for soldiers waiting in reserve.

Rifleman
Soldiers would spend up to two hours on guard duty here, keeping an eye out for an enemy offensive.

Fire step
This raised platform allowed soldiers to reach over the trench wall, which was usually slightly higher than the height of a man to avoid the enemy being able to see inside.

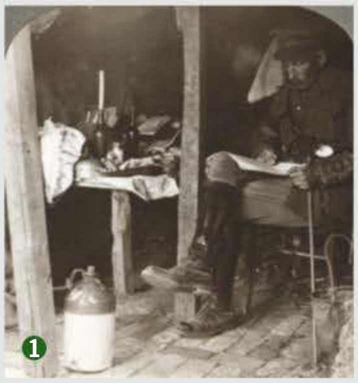
Job roles in the trenches

The majority of soldiers in the trenches were there to directly engage in combat. These soldiers would have a spectacular range of abilities and experiences. Some may have been grizzled war veterans, while others would be fresh recruits, straight out of training. These people would be responsible for day-to-day maintenance, guarding and, eventually, going over the top and launching an offensive on the German trenches.

Officers ① would also be stationed in the trench. They would be soldiers of higher status and would be in charge of organising and leading night patrols, which tried to keep track of the enemy's location. They had marginally more luxury than the other soldiers, sleeping in a proper dugout in the trench and having first pick of the food.

Medics ② were stationed in three positions: the collecting zone (right by the battlefield), the evacuating zone (between the front and rear trenches) and the distributing zone (where they would treat the wounded in pop-up hospitals). If a soldier couldn't be moved, they would be treated where they lay. The Royal Army Medical Corps (RAMC) is the only part of the British army in which two members hold double Victoria Crosses.

Listeners ③ would move through tunnels closer to the enemy's front line than the trenches. The idea was to try to hear enemy plans and put a halt to the enemy planting mines close to their trench. This was a very dangerous role as tunnels could collapse at any time.


①

②

③

A day on the front line

Soldiers in the British army fighting in WWI would spend about 15 per cent of their active service on the front line and 40 per cent in the reserve trenches.

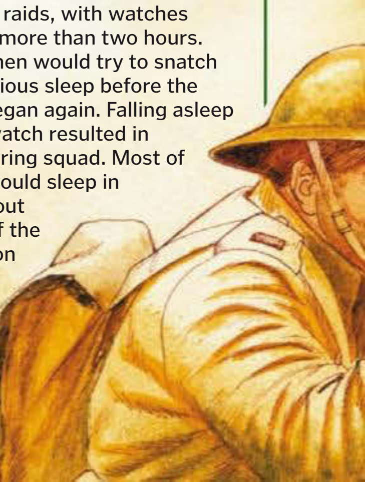
The average day on the front line would begin with a stand to. This would be around an hour before sunrise and involved all soldiers standing on the fire step, rifles ready and bayonets fixed. They would then begin the 'morning hate', firing their guns into the morning mist. This had the dual benefit of relieving tension and frustration, as well as helping to deter a possible dawn raid.

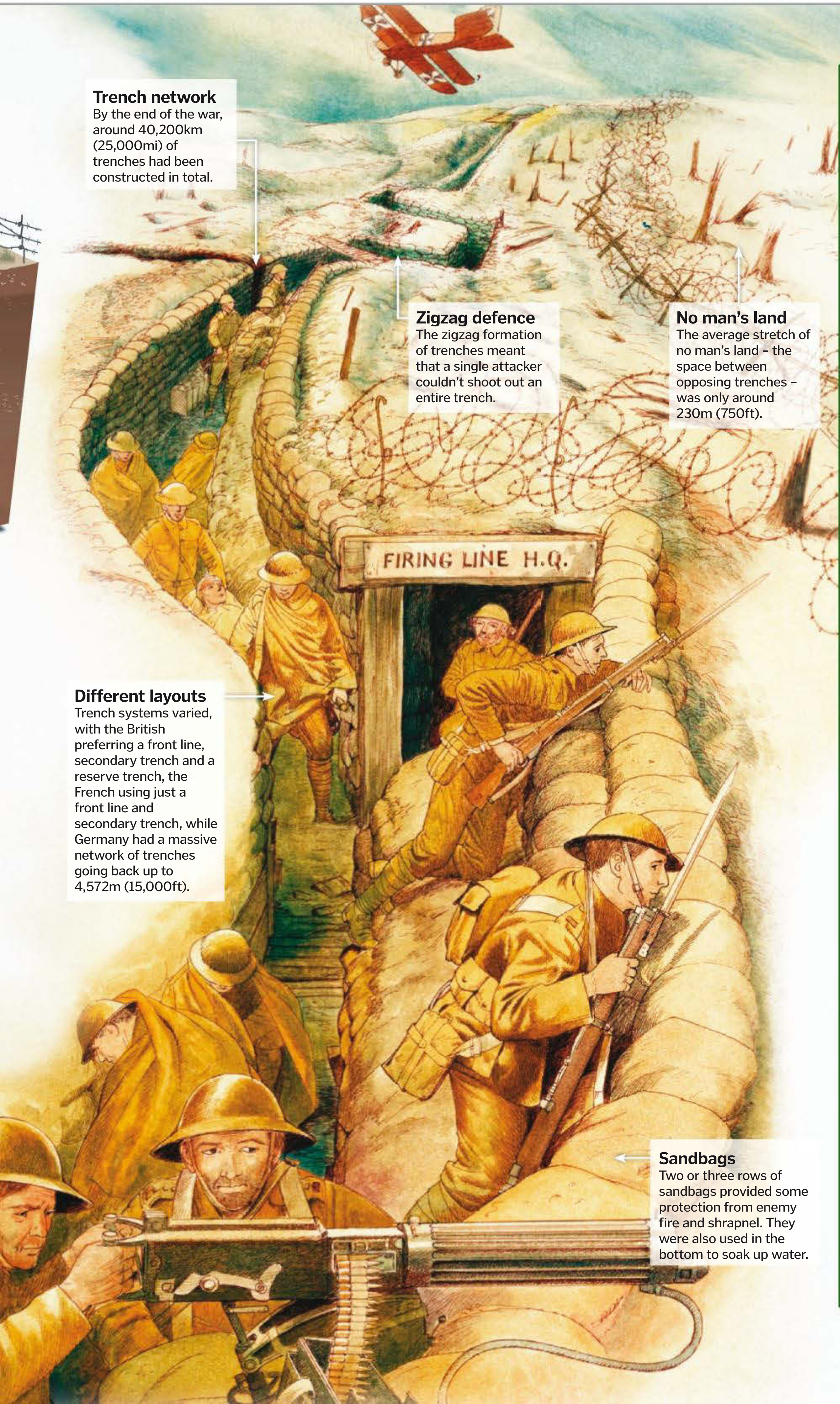
Breakfast would then be served, consisting of biscuits or bread and canned or salted meat. Following breakfast would be a period of chores. These could range from cleaning weapons and fetching rations to guard duty and trench maintenance. The latter would often involve repairing shell damage or trying to shore up the damp, underfoot conditions.

One of the main challenges in everyday trench life was the food. At the start of the war, each soldier received 283 grams (ten ounces) of meat and 227 grams (eight ounces) of vegetables per day. However, as the war wore on, the meat allowance reduced to 170 grams (six ounces) of meat and, if you weren't on the front line, you only got meat on nine out of 30 days. Diets were bulked out with corned beef, biscuits and bread made of dried ground turnips. As the kitchens were so far behind the front line, it was nearly impossible to provide hot food to the troops at the front, unless the men pooled their resources and bought a primus stove to heat their food and make tea. Other common meals often included a pea soup with horse meat and Maconochie, a weak soup containing sliced carrots and turnips.

As dusk fell, the soldiers would engage in an evening version of the morning hate. Essential tasks like repairing barbed wire and rotation of troops were done after dark, as the enemy was less likely to be able to launch an effective attack.

Guards would look out for night-time raids, with watches lasting no more than two hours. Off-duty men would try to snatch some precious sleep before the process began again. Falling asleep while on watch resulted in death by firing squad. Most of the men would sleep in hollowed-out sections of the trench or on the fire step.




FIRING LINE H.Q.

Trench network
By the end of the war, around 40,200km (25,000mi) of trenches had been constructed in total.

Zigzag defence
The zigzag formation of trenches meant that a single attacker couldn't shoot out an entire trench.

No man's land
The average stretch of no man's land – the space between opposing trenches – was only around 230m (750ft).

Different layouts
Trench systems varied, with the British preferring a front line, secondary trench and a reserve trench, the French using just a front line and secondary trench, while Germany had a massive network of trenches going back up to 4,572m (15,000ft).

Sandbags
Two or three rows of sandbags provided some protection from enemy fire and shrapnel. They were also used in the bottom to soak up water.

5 key WWI weapons

1 Machine gun
The machine gun was one of the definitive weapons of WWI. At the outbreak of war, Germany had 12,000 machine guns, while the British and French only had a few hundred between them.

2 Tank

Early tanks were based on farming vehicles, the caterpillar tracks allowing for movement over uneven muddy ground. They were slow and unreliable but once these problems were ironed out and they were weaponised, the British enthusiasm for the tank helped them win the war.

3 Rifle
Despite the advance of long-range or automatic weapons like machine guns and mortar shells, the rifle continued to be an essential piece of military kit for soldiers.

4 Bayonet
These blades affixed to the front of rifles were only useful in close combat. The French army used needle blades, while the German army developed the saw-back bayonet blade.

5 Flame-thrower

By 1915, German soldiers had portable flame-throwers that terrified the British army at Flanders. The British attempted to come up with flame-throwers of their own, but with little success, while the French developed their own self-igniting, lightweight flame-throwers, with more success than the British.

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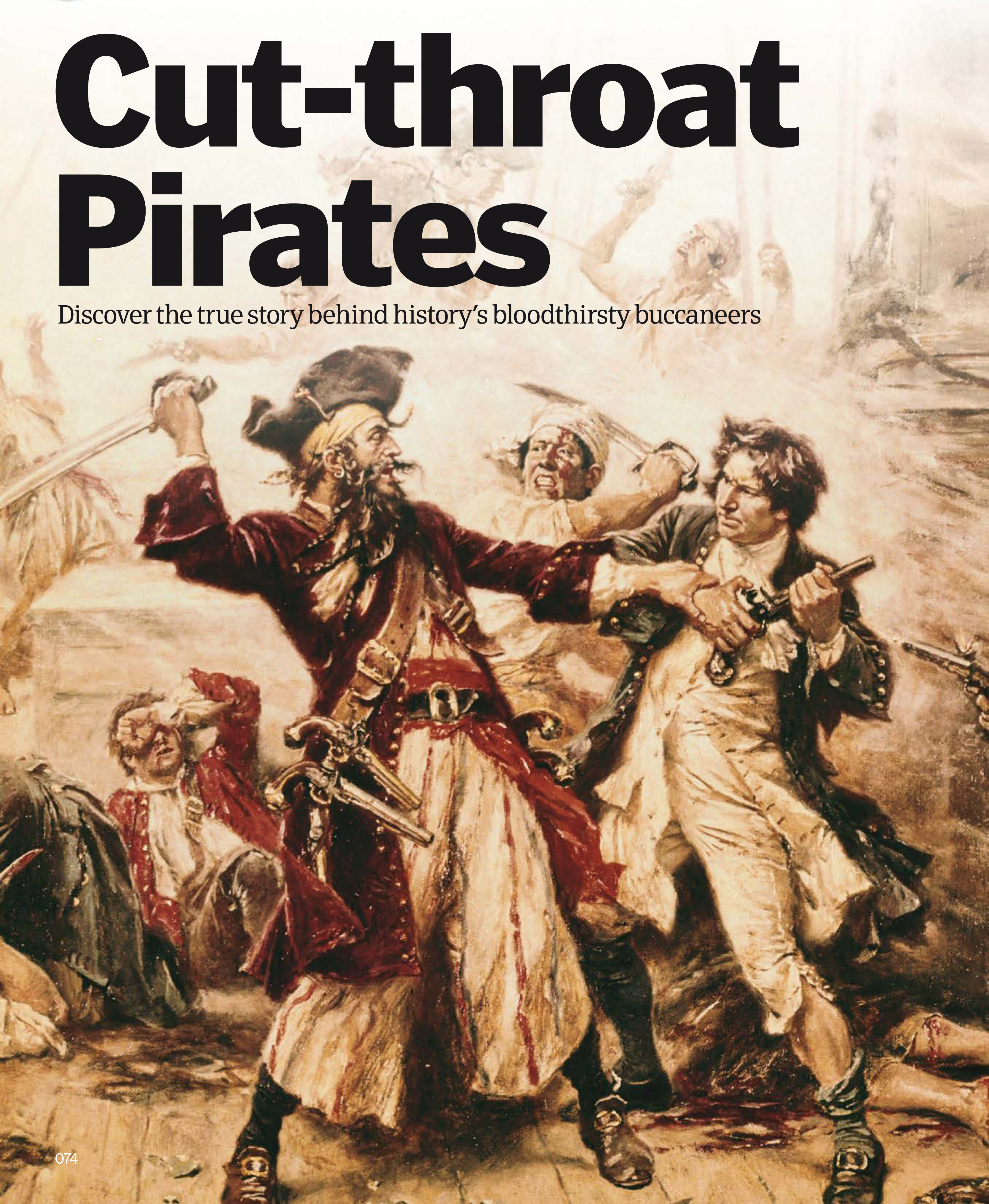
Cut-throat Pirates

Discover the true story behind history's bloodthirsty buccaneers



DID YOU KNOW? *Without surgeons on board, the ship's cook often performed amputations, as they could handle a knife best*

In the 1600s, the ghoulish sight of the Jolly Roger could strike fear into the hearts of even the bravest seamen. Pirates had existed for as long as man had sailed the seas, but it was at this time that they truly began to rule the waves.

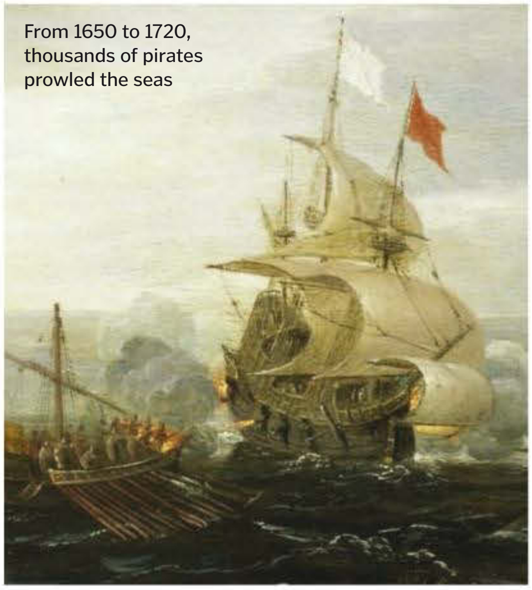
The colonisation of the New World and the birth of the slave trade meant that the oceans were swarming with richly laden merchant ships, and many men and women turned to a life of crime on the high seas. And what a life it was! A bottle of rum at breakfast and a buxom wench at supper, and in between a day spent stalking ships and trading spoils in pirate havens.

These hives of villainy, hidden away on islands in the Caribbean and Indian Oceans, served as launch sites for raids on enemy outposts and merchant ships. Here, pirates could repair their vessels away from the watchful eye of the Navy, while taverns, gambling halls and brothels provided welcome respite for pirates who had spent months at sea.

Over the years, pirates' lives became easier and even more lucrative. Sailors knew these bandits were skilled, well-armed, and willing to risk it all – the chance of winning a battle with them was slim. Ships that did put up a fight were shown no mercy, so their best option was to raise the white flag and surrender.

However, as the problem of piracy grew, merchant communities began to take matters into their own hands, arming and equipping ships at their own expense to protect commerce. These ships, captained by 'privateers', were licensed by the crown and could attack any enemy vessel. Over time, the line between privateer and pirate became blurred.

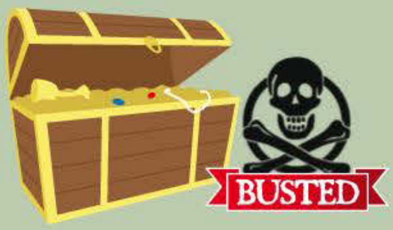
In a world where native populations were being wiped out or bound in chains, pirate life represented freedom and democracy. It's easy to see why many found it hard to resist the spoils of the Golden Age of Piracy.



From 1650 to 1720, thousands of pirates prowled the seas

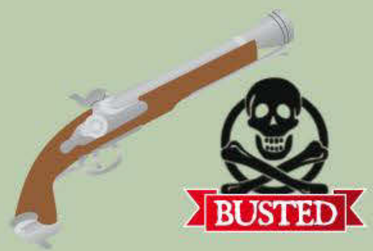
Pirate myths busted

Think you know these fearsome seafaring fiends? Think again, as we expose the truth behind the tales



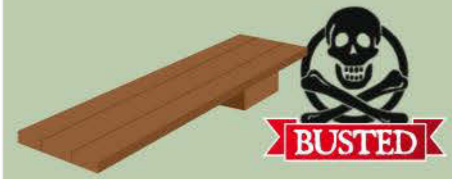
They buried their treasure

Loot was spent or sold immediately – a pirate's life was far too short for forward thinking.



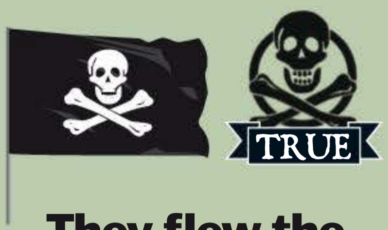
They were brutal and bloodthirsty

It was much easier to capture a ship without conflict, so pirates encouraged them to surrender peacefully.



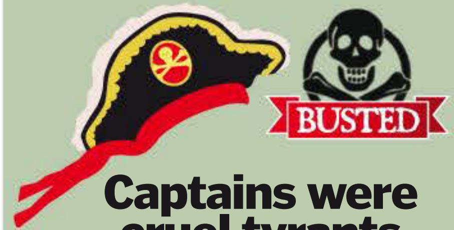
People had to walk the plank

Anyone who did not surrender was simply thrown overboard – there was no time for elaborate ceremonies.



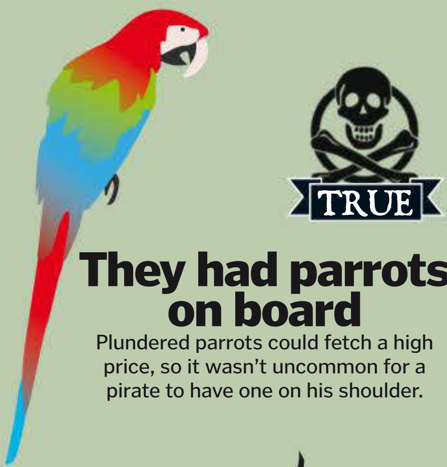
They flew the Jolly Roger

Initially flying a national flag to lure in victims, they quickly replaced this with the chilling skull and crossbones.



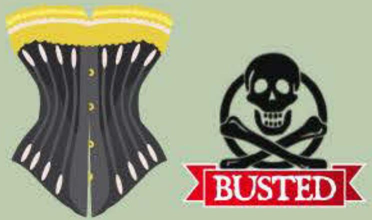
Captains were cruel tyrants

Pirate captains were elected democratically. If they stepped out of line, the crew could depose them.



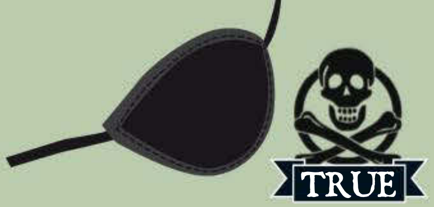
They had parrots on board

Plundered parrots could fetch a high price, so it wasn't uncommon for a pirate to have one on his shoulder.



Pirates were always men

Anne Bonny and Mary Read are just two of many female pirates that set sail, although both dressed as men.



They had peg legs and eye patches

Given the dangerous nature of their jobs, many pirates did lose a limb or an eye along the way.

Spoils of the New World

The discovery of the Americas not only fuelled economies, but also a reign of terror

When Spanish explorer Christopher Columbus set sail on what he believed to be a westward route to Asia, no one could have predicted that instead he would stumble across one of the most resource-rich continents in the world.

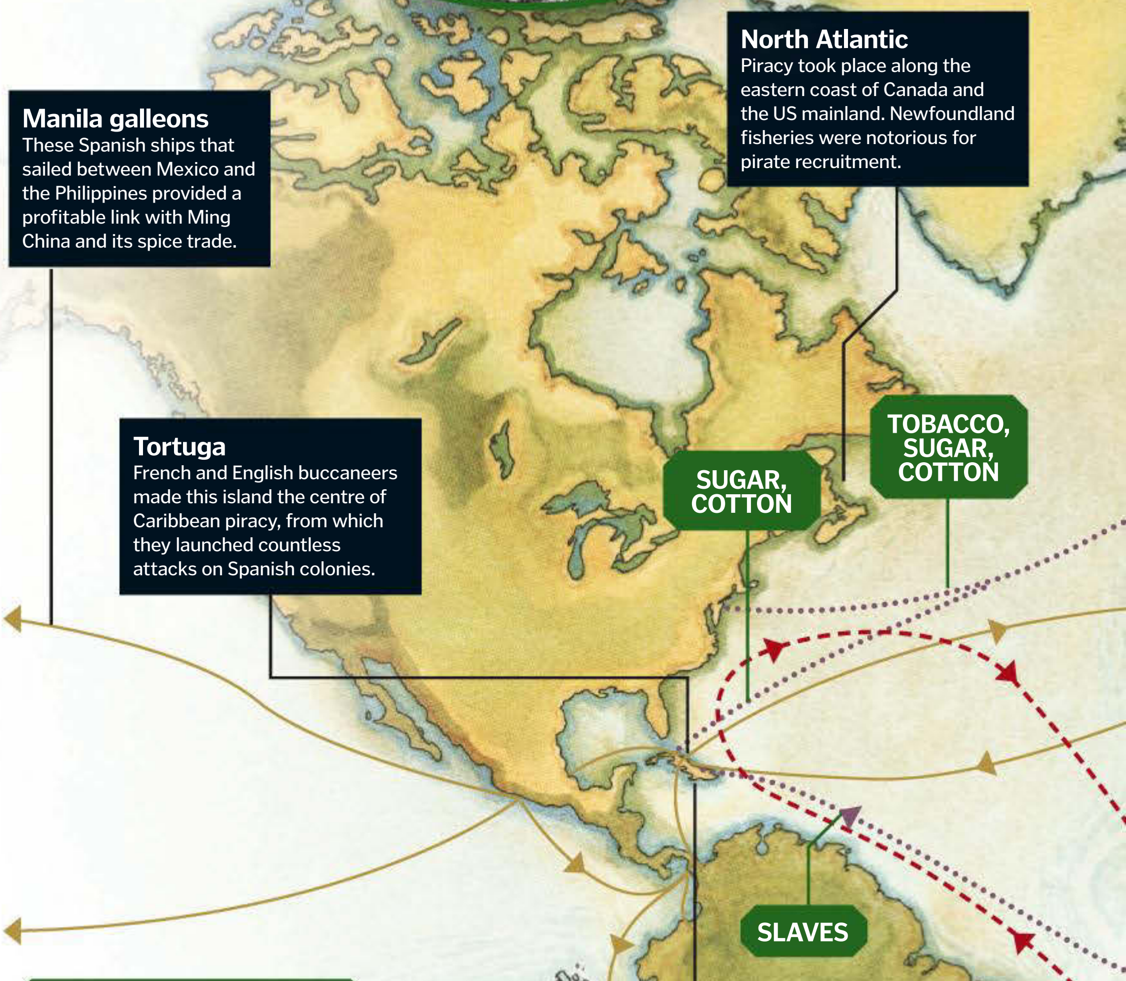
He returned from the Americas laden with gold, pearls and a strange plant called 'tobacco', kick-starting an era of frantic colonisation by Spain and other European powers, including the English, Portuguese and Dutch. They quickly began stripping the new land and sending back ships laden with its bounties.

As wars between the colonisers waged, many settlers and sailors cottoned on to the riches that these galleons had to offer. By the 1630s, buccaneers were in operation in the Caribbean, mostly made up of Frenchmen who had been driven off the island of Hispaniola by the Spanish. They relocated to the island of Tortuga, which provided limited resources on which to live. It was partly in retaliation and partly out of necessity that these buccaneers began attacking Spanish ships, plundering them for every penny.

The English, French and Dutch embraced these newly established pirates as they dealt a much-needed blow to the ever-strengthening Spanish. The English capture of Jamaica only served to bolster piracy, as its early governors semi-legitimised piracy and offered a safe haven in Port Royal – in return for a slice of the precious booty.

As Spain's power waned, the appeal of piracy faded with it, and letters stating legitimacy became harder to obtain. The buccaneers needed a new hunting ground. Rumours of ships laden with precious silks and spices sailing unprotected through Indian waters soon reached the rotten bunch, and in 1693, pirate captain Thomas Tew decided to seek one out. Setting sail from Bermuda, Tew cornered the Cape of Good Hope and cruised along the East African coast to the Red Sea, where he ran down a ship sailing from India to the Ottoman Empire. Despite its enormous crew, the ship surrendered and Tew's pirates helped themselves to £100,000 worth of gold and silver, as well as ivory, spices, gemstones and silk. The route, which was dubbed the Pirate Round, became one of the most profitable on the planet.

Pirate Henry Every captured a Mughal trading ship carrying £600,000 worth of goods

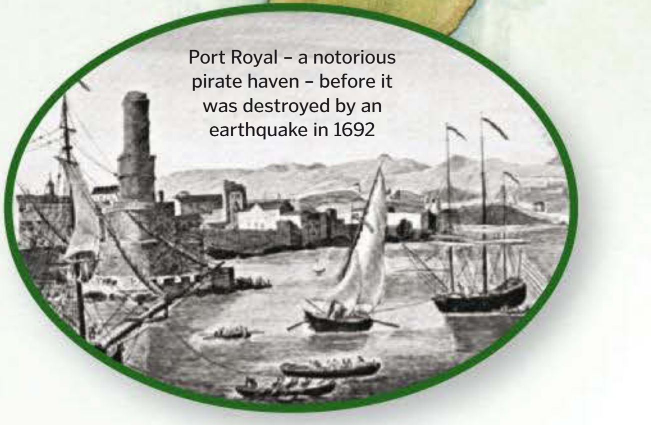


Manila galleons
These Spanish ships that sailed between Mexico and the Philippines provided a profitable link with Ming China and its spice trade.

North Atlantic
Piracy took place along the eastern coast of Canada and the US mainland. Newfoundland fisheries were notorious for pirate recruitment.

Tortuga
French and English buccaneers made this island the centre of Caribbean piracy, from which they launched countless attacks on Spanish colonies.

Port Royal
This Jamaican town was crawling with criminals, with hundreds of brothels and taverns for pirates to spend their loot at.



Port Royal – a notorious pirate haven – before it was destroyed by an earthquake in 1692

Precious cargo

Tobacco
Plunder like tobacco fetched a high price – if the pirate could bear to part with it.

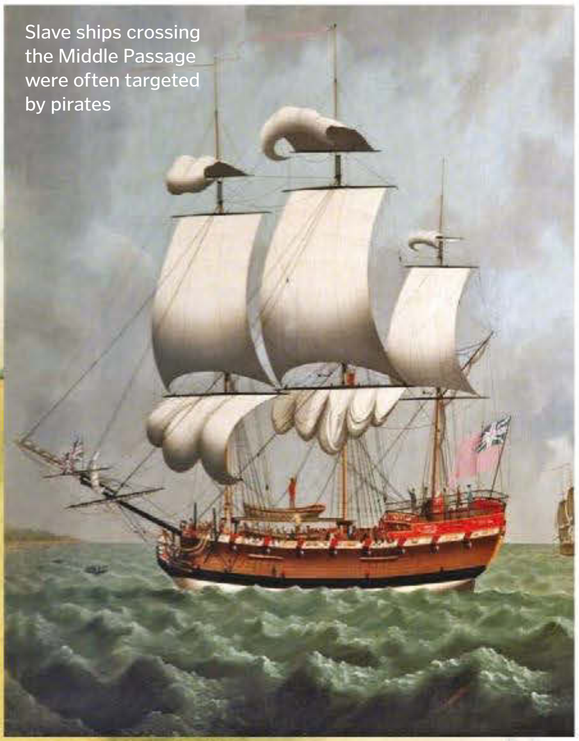
Gold
Really lucky pirates might have stumbled across a vessel shipping Aztec treasures from Mexico to Spain.

Slaves
Not only could captured slaves be sold on, they could also be ransomed or made part of the crew.

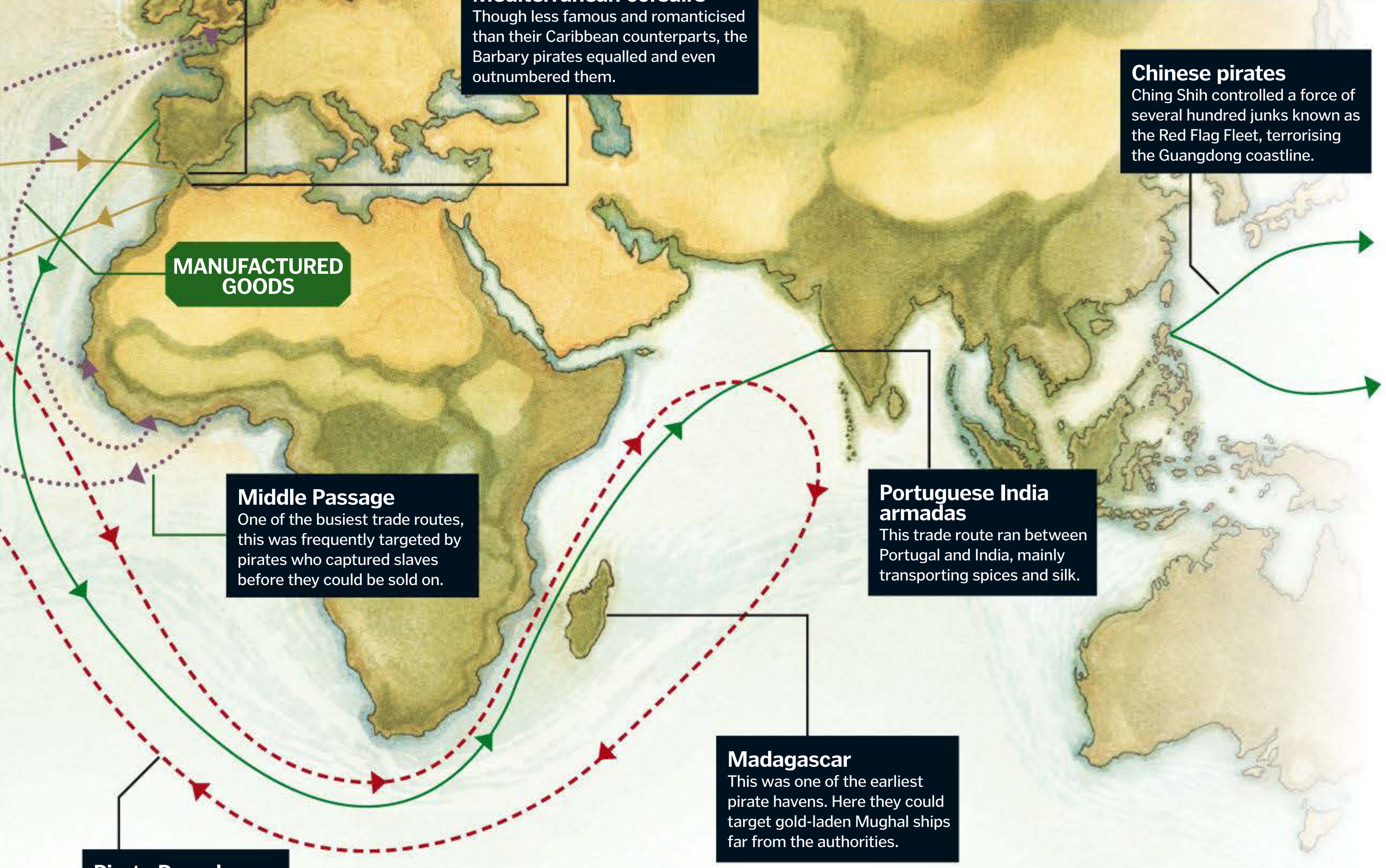
DID YOU KNOW? *Africans and African-Americans, often escaped slaves, made up a substantial part of the pirating force*

Trade routes of the Golden Age

As shipping flourished between Europe and its colonies, so too did these pillaging pirates



Slave ships crossing the Middle Passage were often targeted by pirates



Spanish treasure fleets

Among the most sought-after ships were those that carried gold and silver from the New World to Seville.

Mediterranean corsairs

Though less famous and romanticised than their Caribbean counterparts, the Barbary pirates equalled and even outnumbered them.

Chinese pirates

Ching Shih controlled a force of several hundred junks known as the Red Flag Fleet, terrorising the Guangdong coastline.

Middle Passage

One of the busiest trade routes, this was frequently targeted by pirates who captured slaves before they could be sold on.

Portuguese India armadas

This trade route ran between Portugal and India, mainly transporting spices and silk.

Madagascar

This was one of the earliest pirate havens. Here they could target gold-laden Mughal ships far from the authorities.

Pirate Round

Buccaneers known as 'Roundsmen' haunted this route, targeting East India Company ships sailing between Britain and India.

> "Settlers and sailors cottoned on to the riches the galleons had to offer"

© Thinkstock; WIKI

Pirates Vs privateers

Tasked with keeping waters safe, privateers became as brutal as pirates themselves

Merchant vessels were a tempting target not only for opportunists, but also for rival countries. It was the English who first commissioned privateers to protect their cargo while in transit, issuing them with licenses to attack any ship that posed a threat. However, as time went on, the promise of plunder became just as legitimate a reason for battle as self-defence. Rather than a wage, privateers were paid with an agreed share of the takings, and the line between piracy and privateering became very blurred indeed.

On the face of it, the difference between these two vocations was simple. Pirates were criminals who acted alone, while privateers worked under the order of the crown. But the methods and end goals were the same. When Elizabeth I came to power, she encouraged merchants to keep port towns safe by preventing pirate ships from entering sea lanes. Anglo-Spanish relations were deteriorating, and war seemed inevitable. By allowing privateers to attack Spanish ships, Elizabeth could deny any direct involvement, while still getting a share of the profits. Her 'sea dogs', as they became known, included explorers Francis Drake and Walter Raleigh, but the Spanish saw them as simply state-sponsored pirates. Throughout this turbulent era, the status of many captains and crews swung between privateer and pirate depending on the state of international affairs and the paperwork they carried.

Many privateers were knighted, but others were not so lucky. In 1701, Scottish sailor William Kidd was hanged for piracy. He had set sail several years earlier with a government commission to suppress pirates in the Indian Ocean. Here, like many privateers of the time, he began to plunder foreign vessels indiscriminately, but conflict was growing among his crew. When they threatened mutiny, he struck the ship's gunner on the head with an ironclad bucket, delivering him a slow and painful death. When Kidd returned to the West Indies, he discovered he had been declared a pirate, and was arrested and sent back to England. After his hanging, Kidd's body was gibbeted over the River Thames as a warning to any would-be pirates.

Hall of infamy

Historical records indicate that some pirates amassed incredible fortunes

Samuel 'Black Sam' Bellamy

The richest pirate in history, Black Sam treated his captives with mercy and likened himself to Robin Hood.

ESTIMATED EARNINGS

$120 million

Thomas Tew

With his flagship the Amity, Tew mapped one of the most infamous routes of the Golden Age – the Pirate Round.

ESTIMATED EARNINGS

$103 million

Bartholomew 'Black Bart' Roberts

Considered the most successful pirate of the era, Black Bart captured a staggering 470 ships.

ESTIMATED EARNINGS

$32 million

Henry Morgan

Perhaps now best known for the rum named after him, 400 years ago Morgan was renowned for his brutal raids.

ESTIMATED EARNINGS

$13 million

Edward 'Blackbeard' Teach

The terrifying sight of Teach and his notorious beard would make any sensible captain surrender immediately.

ESTIMATED EARNINGS

$12.5 million

Edward England

England started out as a privateer, but pledged his allegiance to piracy after being captured.

ESTIMATED EARNINGS

$8 million

Stede Bonnet

Nicknamed the Gentleman Pirate, Bonnet turned to a life of crime after growing tired of his upper class background.

ESTIMATED EARNINGS

$4.5 million

Charles Vane

This pirate was infamous for his barbaric leadership style, and loved nothing more than to torture his crew members.

ESTIMATED EARNINGS

$2.3 million

Edward Low

Low became a pirate after his wife died in childbirth. He was known for his horrifically creative torture methods.

ESTIMATED EARNINGS

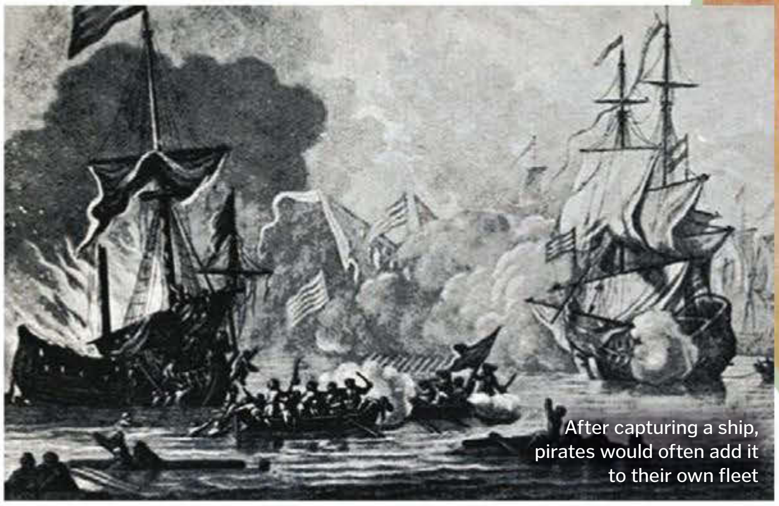
$1.8 million

John 'Calico Jack' Rackham

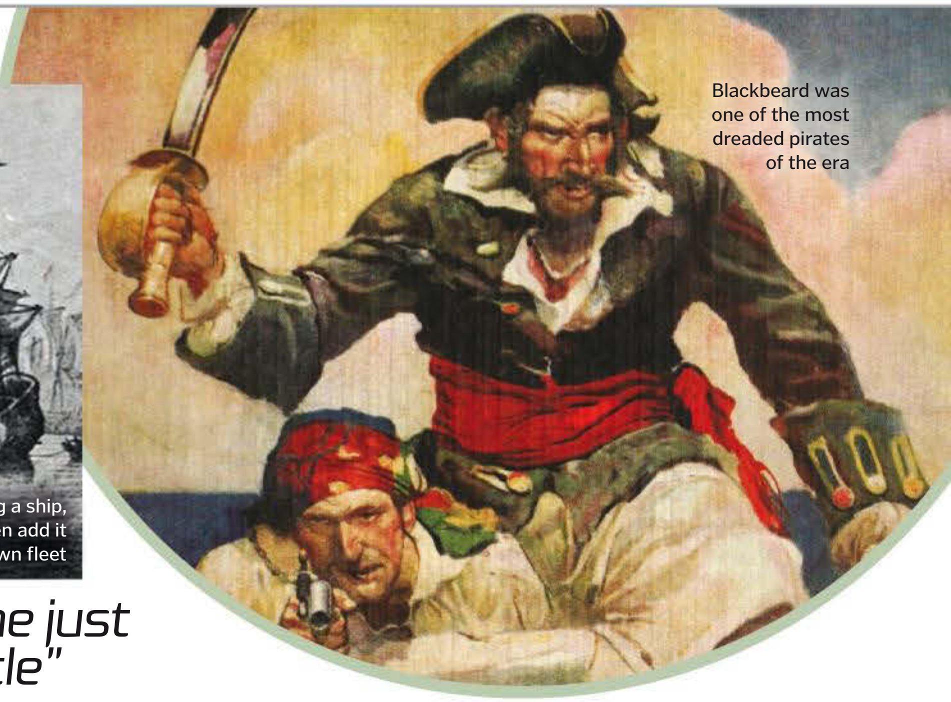
Calico Jack designed the Jolly Roger, and had two infamous female pirates in his crew – Mary Read and Anne Bonny.

ESTIMATED EARNINGS

$1.5 million



After capturing a ship, pirates would often add it to their own fleet

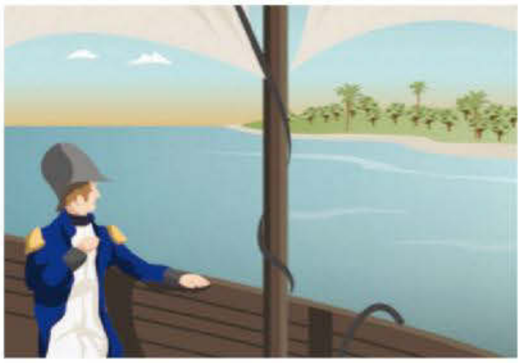


Blackbeard was one of the most dreaded pirates of the era

"The promise of plunder became just as legitimate a reason for battle"

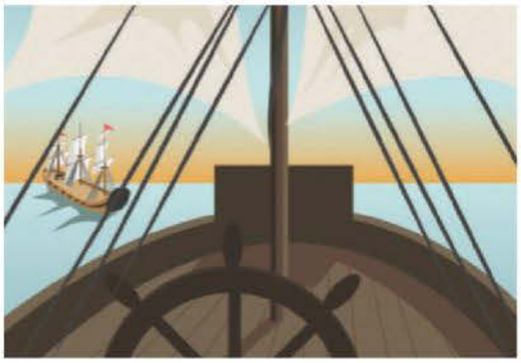
Seizing merchant vessels

Far from being spontaneous attacks, pirate raids were meticulously planned



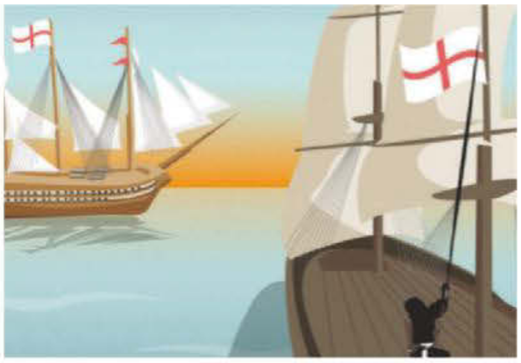
1 The perfect location

Not only was the Caribbean the epicentre of trade between Europe and the colonies, it was also teeming with uninhabited islands and secluded coves in which pirates could covertly lie in wait for their prey.



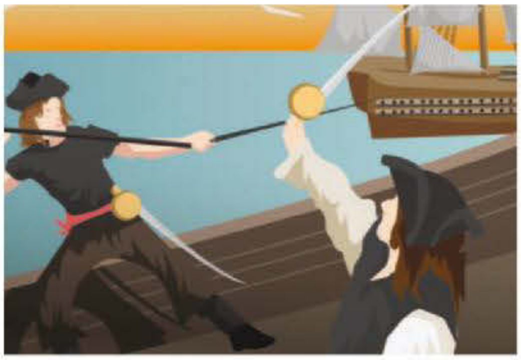
2 Gathering intelligence

Pirates didn't attack any old ship. On land, they would eavesdrop in taverns to find out what cargo was to be transported and when, and at sea they would stalk targets to find out how many men and weapons were on board.



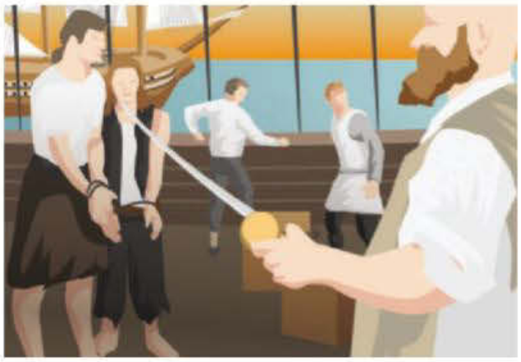
3 Raising the Jolly Roger

The sight of the dreaded skull and crossbones often scared sailors into surrendering peacefully, but before it was raised, pirates flew the flag of the victim ship to lull them into a false sense of security.



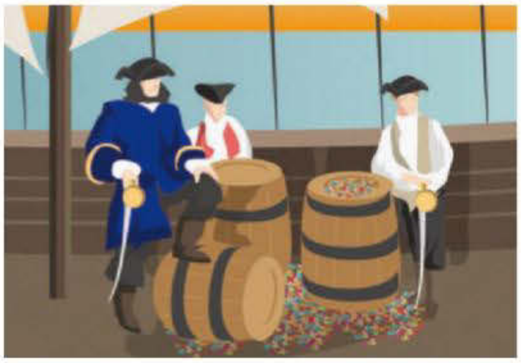
4 Attack!

A warning shot was fired to signal an imminent attack. Grappling hooks were used to pull the ship close enough for the pirates to board and wooden wedges were jammed into the rudder to prevent it from being steered.



5 Dealing with the enemy

What do you do with a captured sailor? Well, there were a few options. Pirates could hold them for ransom, integrate them into their crew, or keep them as slaves. Anyone who tried to fight back would be thrown overboard.



6 The booty

The sailors were stripped of any valuables and the cargo holds ransacked. The loot would then be divided up between the crew, with the captain receiving the biggest portion. The ship would be added to the pirate fleet or sunk.

© WIKI; Illustrations by Marcus Faint/ Ed Crooks

Queen Anne's Revenge

Like her captain, this infamous pirate ship started life in the Royal Navy

Despite his legendary reputation, little is known about why a young sailor named Edward Teach decided to grow out his beard and turn to a life of piracy. Blackbeard, as he became known, is believed to have lived in Bristol before setting sail for the Caribbean, where he worked on privateer ships during Queen Anne's War. In around 1716, he joined the crew of renowned pirate Benjamin Hornigold, and later that year he was placed in command of his own sloop.

It was in autumn 1717 that Blackbeard and his fellow pirates captured the French slave ship La Concorde – originally a Royal Navy ship – off the coast of Martinique. With the French crew already weak with dysentery and scurvy, they hastily surrendered, and the ship fell into Blackbeard's hands. He made her his flagship and renamed her Queen Anne's Revenge, and for several months he cruised the Caribbean, plundering ships along the way.

By May 1718 he had reached Charleston, South Carolina, and it was here where he made one of the most audacious moves of his career: he blockaded the Charleston harbour. Demanding a ransom of a chest of medicine, his demands were eventually met, but it was not enough to save his beloved flagship. On leaving the port, Queen Anne's Revenge ran aground, and Blackbeard was forced to abandon ship.

The decline of piracy

TRATADO DE PAZ, ... DE ESPAÑA, Y DE INGLATERRA, EN UTRECH ...

Año 1713.

TRACTATUS PACIS & AMICITIÆ ...

TREATY OF PEACE and FRIENDSHIP BETWEEN ...

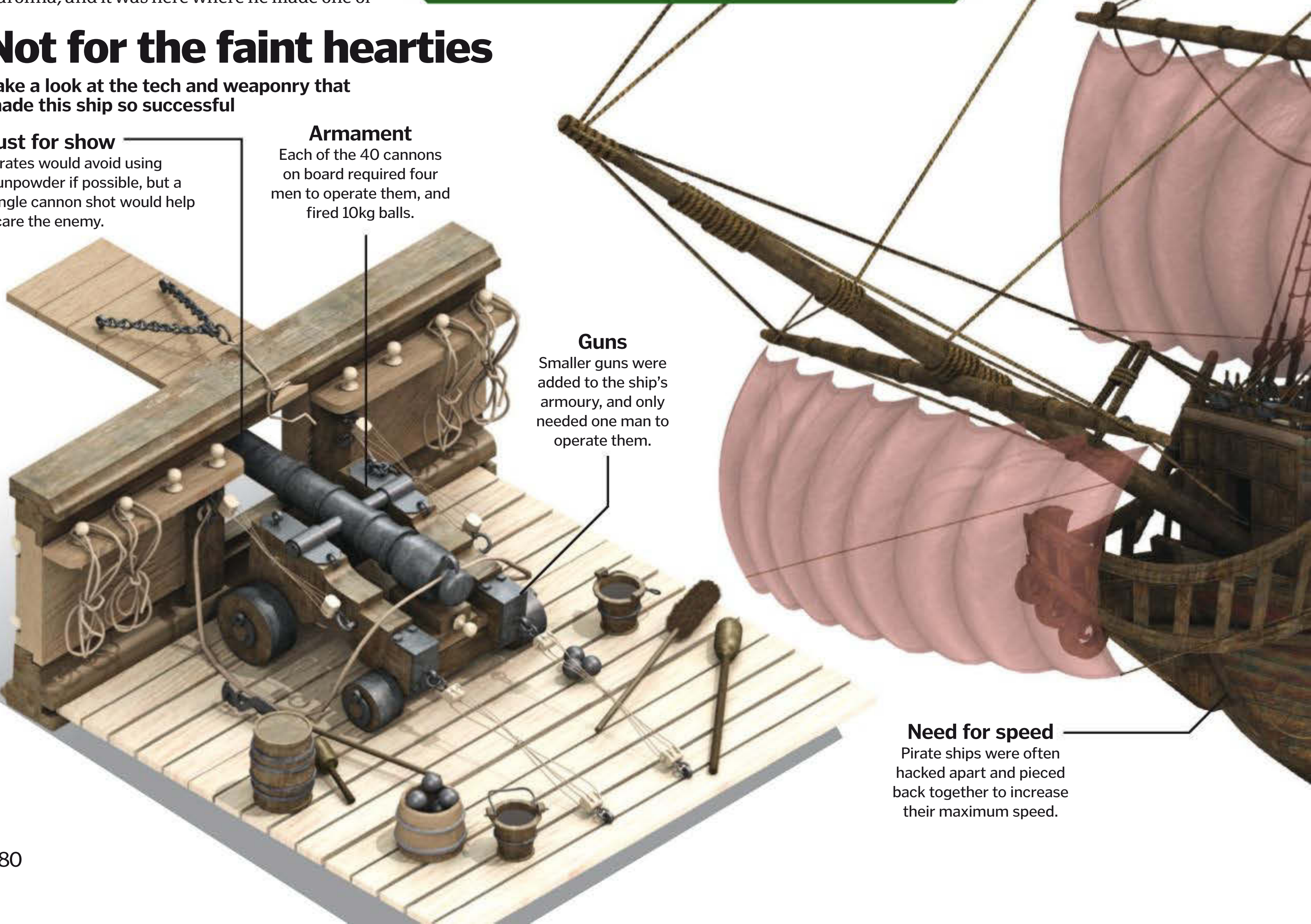
LONDON ...

By the 18th century, nations had grown weary of the sea battles that waged between the belligerents of the Spanish Succession. In 1713, a peace treaty recognised Philip, Duke of Anjou, as King of Spain, ending the chance of French rule. Many of Spain's colonies were divided up between European states, and the war ended the following year.

With this newfound peace came a surplus of sailors, previously employed as privateers or by their nation's navy. Initially this led to an increase in piracy, but in response European countries bolstered their naval forces. With the lure of Spanish treasure gone, and with navies now patrolling every port, pirates had very little left to live for, and by 1719, most were on the run. The Golden Age of Piracy was dead.

Not for the faint hearties

Take a look at the tech and weaponry that made this ship so successful



Sails
The Queen Anne's Revenge had three masts supporting large sails to catch the sea breezes.

Just for show
Pirates would avoid using gunpowder if possible, but a single cannon shot would help scare the enemy.

Armament
Each of the 40 cannons on board required four men to operate them, and fired 10kg balls.

Guns
Smaller guns were added to the ship's armoury, and only needed one man to operate them.

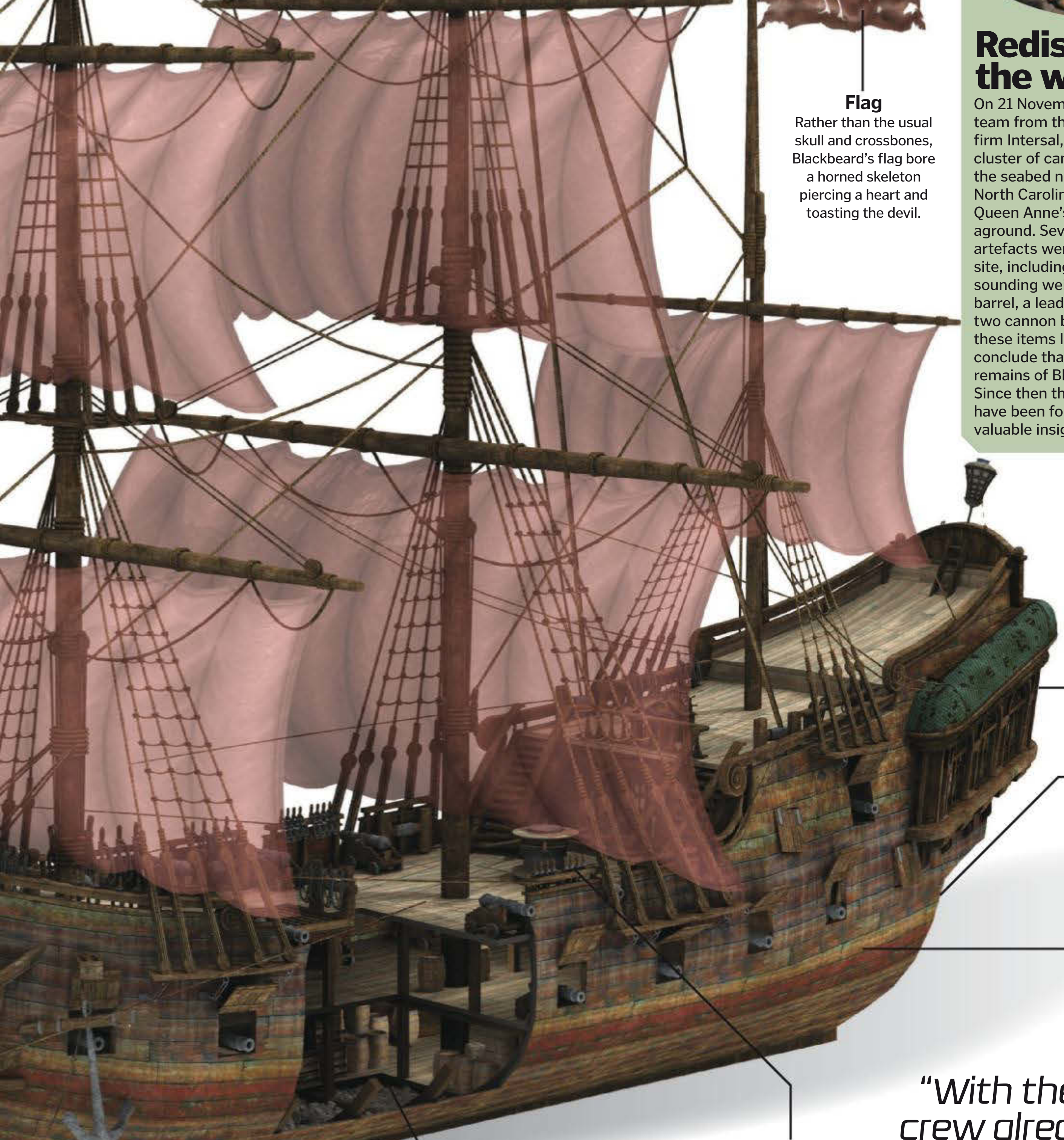
Need for speed
Pirate ships were often hacked apart and pieced back together to increase their maximum speed.

DID YOU KNOW? *Blackbeard followed his beloved flagship to a watery grave in 1718, after being killed in battle with the Royal Navy*

A cannon is recovered from the wreck of Queen Anne's Revenge

Rediscovering the wreck

On 21 November 1996, a search team from the private research firm Intersal, Inc. discovered a cluster of cannons and anchors on the seabed near Beaufort Inlet, North Carolina – the spot where Queen Anne's Revenge had run aground. Several early 18th century artefacts were recovered from the site, including a bronze bell, a sounding weight, a blunderbuss barrel, a lead cannon apron and two cannon balls. The discovery of these items led the researchers to conclude that this was indeed the remains of Blackbeard's flagship. Since then thousands more objects have been found, offering a valuable insight into life on board.



Flag
Rather than the usual skull and crossbones, Blackbeard's flag bore a horned skeleton piercing a heart and toasting the devil.

Blackbeard's quarters
Located at the rear, the captain's cabin was sheltered from the elements and easy to defend in case of a mutiny.

Supplies
Previously a slave ship, the vessel had a huge hold that could store rigging, food and drinking water.

Lucky dip
Merchant ships could be carrying anything from sugar and rum, to gold and jewels.

Anchor
The ship's anchor alone weighed a whopping 1,400kg, and took almost an hour to raise.

The stove in the ship's kitchen was built with brick and a bucket of sand was kept nearby to put out flames.

Torture as a tool
Pirates didn't hesitate to use flogging or keelhauling to extract confessions about hidden treasure.

> *"With the French crew already weak with dysentery and scurvy, they hastily surrendered"*

© Solgo; WIKI; Alamy

Sikorsky MH-60 Black Hawk

Designed for special operations in hostile environments, this was a new kind of war machine, built for a new kind of battlefield

From the chaotic skies over Somalia during the Battle of Mogadishu in 1993, to the covert operation to kill Osama Bin Laden in 2011, Black Hawk helicopters are among the deadliest, most effective tools available to any modern military. After its experiences in the Vietnam War in the 1960s and 70s, the US military knew just how essential it was to have tough, multi-role helicopters available. Not only were these aircraft useful for rapidly transporting combat personnel to and from battlefields, they could even remain on the front line to provide direct support. However, the existing Huey helicopters were out of date.

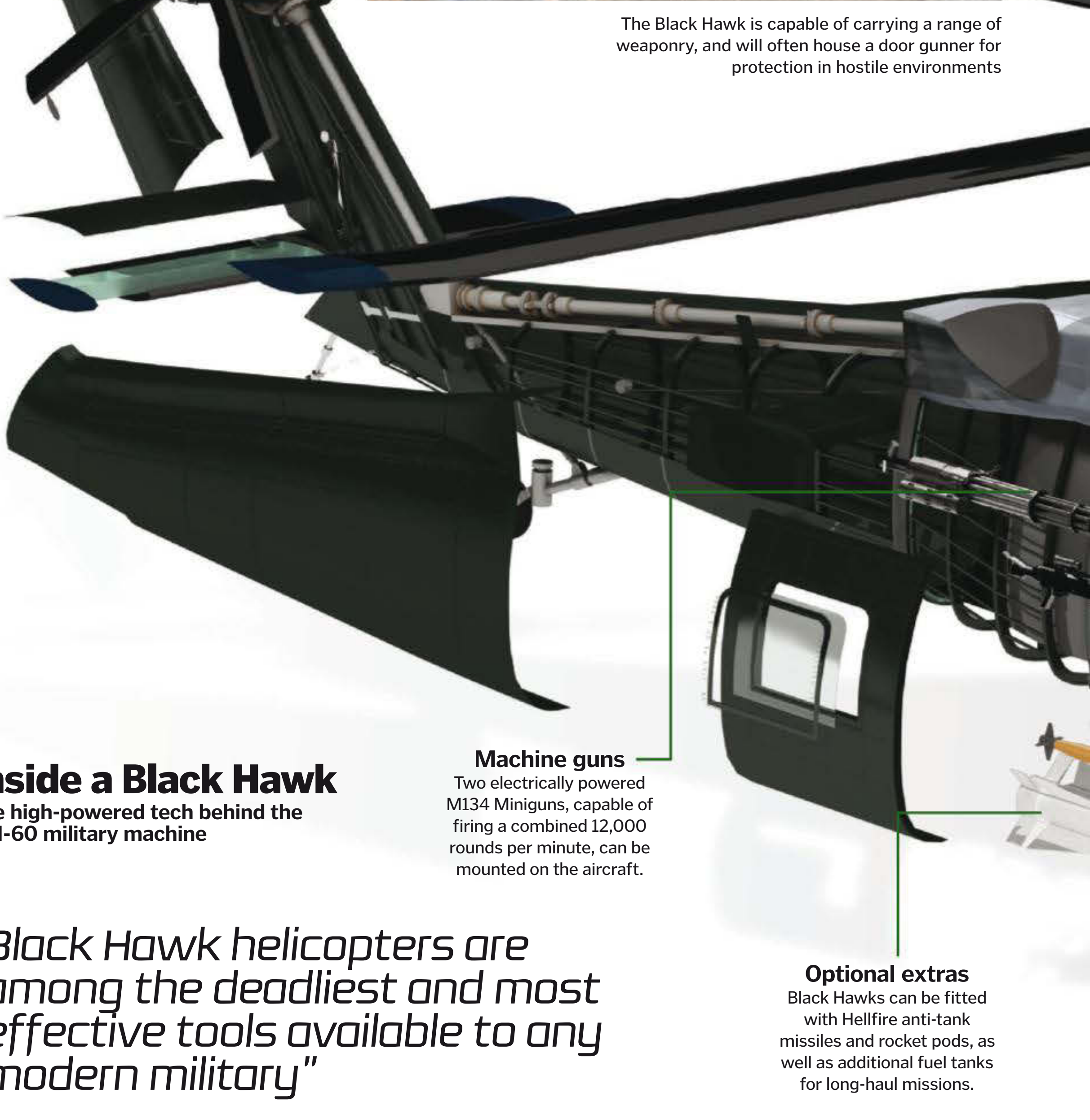
Two US companies, Boeing Vertol and Sikorsky, went head-to-head with their rival designs for the new combat helicopter, with the latter finally winning the contract with its S-70 prototype. Since the model first took to the skies in 1974, a huge number of variants have gone into production, each with its own specific role to play in a combat zone. For instance, the secretive 'MH-X' version – used during the mission to kill Al-Qaeda's chief – was rumoured to be equipped with stealth technology, making it almost undetectable to radar.

The MH-60 variant seen here was developed from the standard UH-60 Black Hawk for use during special operations. The machine's effective range was greatly increased with the addition of a more efficient fuel tank, the installation of systems for aerial refuelling, and the improvement of the craft's overall survivability. It was during a special operation that these assets would be put to the ultimate test, an incident known as Black Hawk Down.

The Black Hawk is capable of carrying a range of weaponry, and will often house a door gunner for protection in hostile environments

Inside a Black Hawk

The high-powered tech behind the MH-60 military machine



Machine guns
Two electrically powered M134 Miniguns, capable of firing a combined 12,000 rounds per minute, can be mounted on the aircraft.

Optional extras
Black Hawks can be fitted with Hellfire anti-tank missiles and rocket pods, as well as additional fuel tanks for long-haul missions.

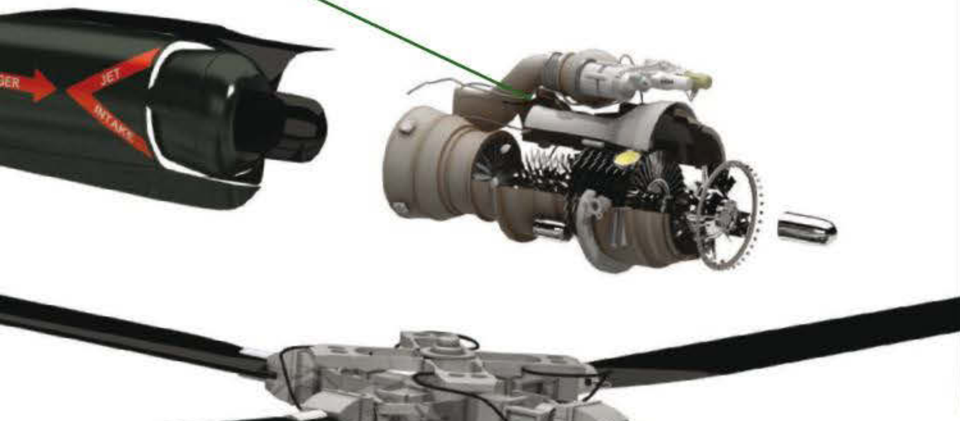
> *"Black Hawk helicopters are among the deadliest and most effective tools available to any modern military"*

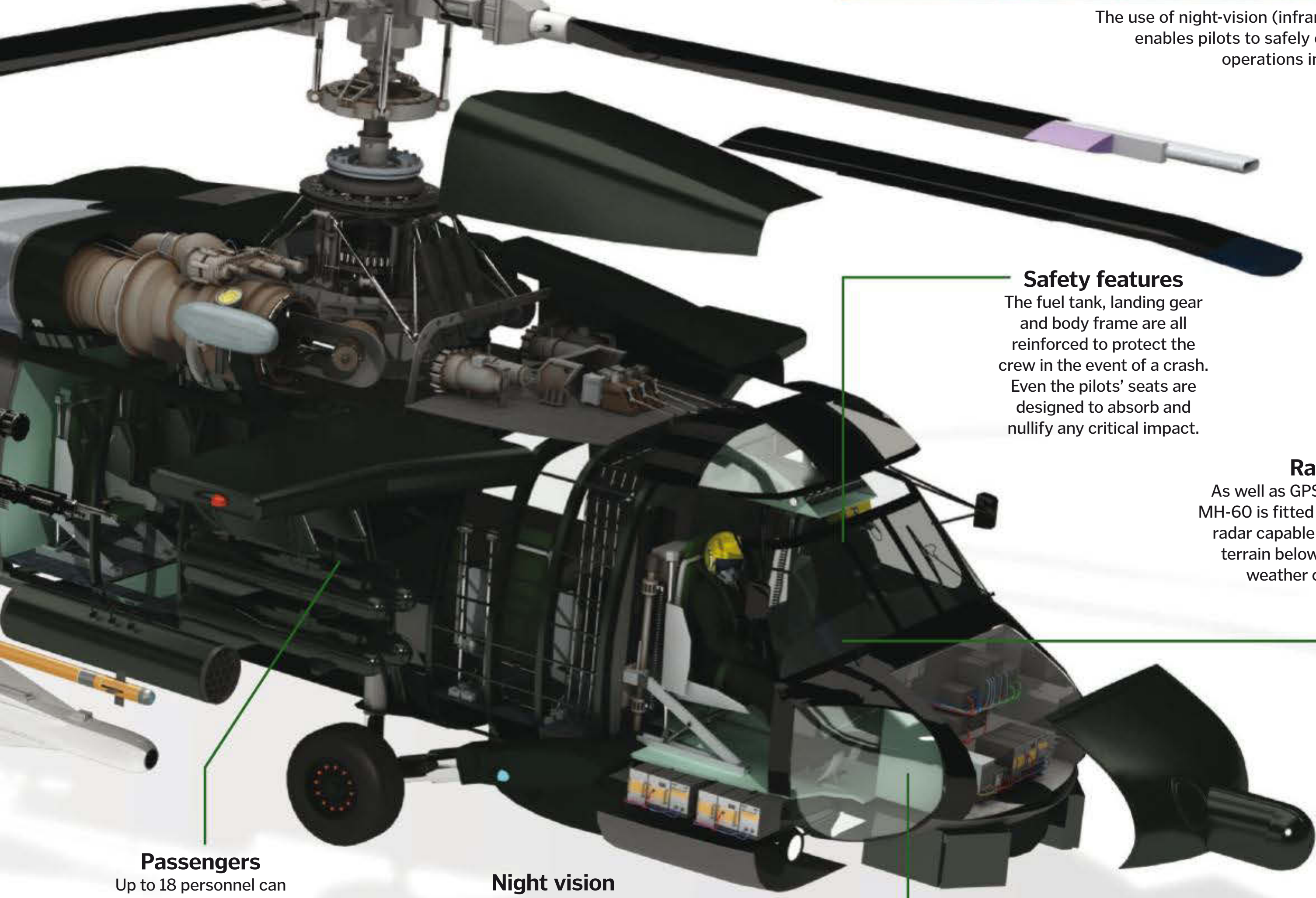
The Battle of Mogadishu

On 3 October 1993, American Rangers flew into Mogadishu, the capital of Somalia, to capture a wanted terrorist leader. They swooped down on the target's base in a convoy of helicopters, with MH-60 Black Hawks hovering overhead to provide support. However, when two of these aircraft came under fire, they crash-landed into the maze of streets and alleyways below. What was supposed to be a smooth operation soon turned into chaos as soldiers battled through the streets to reach the downed aircraft and their stricken crew. The ensuing battle is now most famously known as Black Hawk Down, due to the 1999 book of the same name, which was adapted into the 2001 Oscar-winning film.

A Black Hawk flies over Mogadishu during Operation Restore Hope, a year before the Battle of Mogadishu

The use of night-vision (infrared) technology enables pilots to safely conduct special operations in total darkness





Twin engines

Two General Electric engines pack a combined 3,988 shaft horsepower, enabling the aircraft to reach a top speed of 280km/h.

Safety features

The fuel tank, landing gear and body frame are all reinforced to protect the crew in the event of a crash. Even the pilots' seats are designed to absorb and nullify any critical impact.

Radar

As well as GPS capability, the MH-60 is fitted with multi-mode radar capable of tracking the terrain below, even in poor weather conditions.

Passengers

Up to 18 personnel can be transported in the rear of the aircraft, which has an operational range of over 2,200km.

Night vision

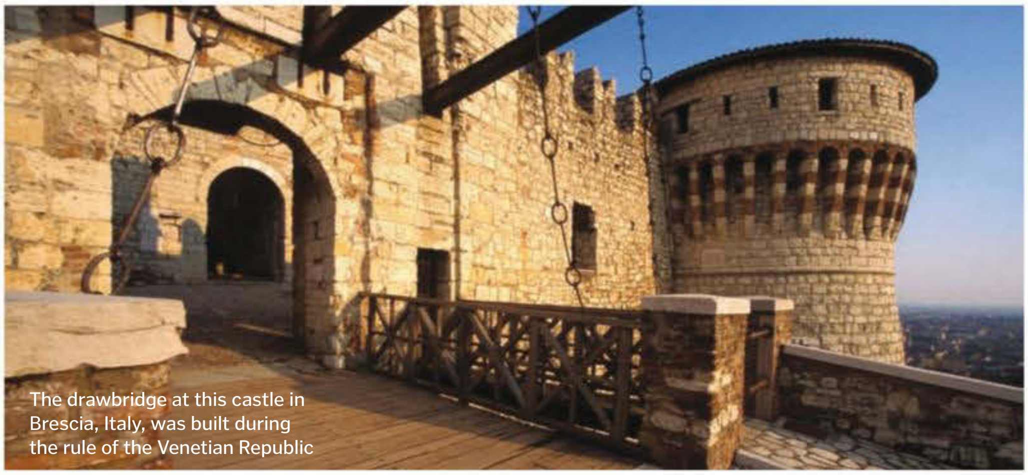
A forward looking infra-red (FLIR) video camera pod captures the surrounding environment and relays it to the pilot, enabling safe flight in total darkness.

© Alamy; WIKI

How drawbridges worked

Used to defend castles for centuries, these fold-up entrances were simple yet effective

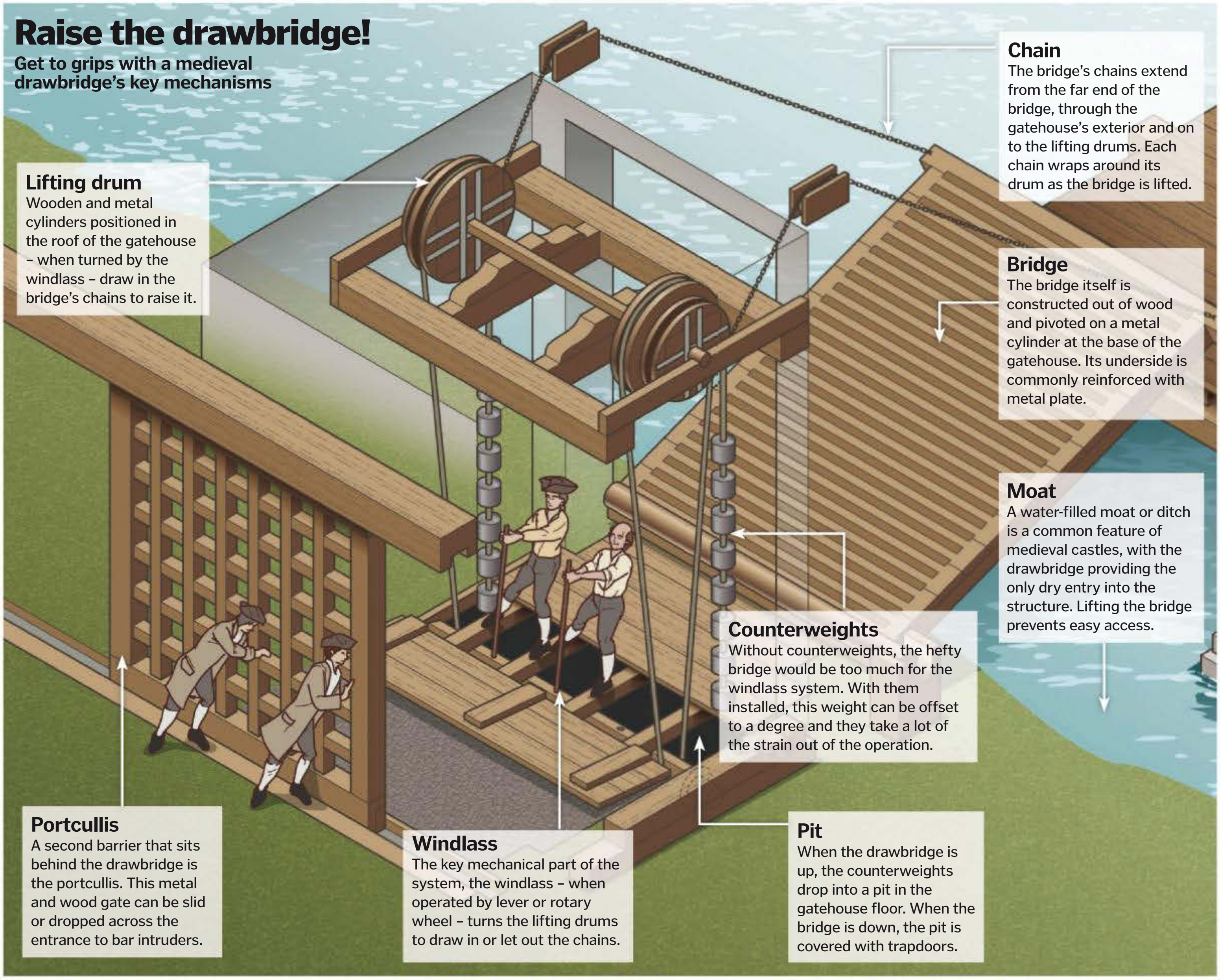
Classical, medieval drawbridges worked via the simple principle of counterweight, with large wood and metal bridges pivoted via a series of balancing weights in a castle's gatehouse. The weights, which were attached to the bridge's lifting chains, enabled the platform to be raised via a windlass, which in turn rotated a pair of lifting drums that gathered in the chains. By employing counterweights, incredibly heavy bridges could be operated by just a few people – useful when under attack. Along with a moat, a reinforced drawbridge served as a two-fold barrier, making it much more difficult for any enemies to invade a fortification or city.



The drawbridge at this castle in Brescia, Italy, was built during the rule of the Venetian Republic

Raise the drawbridge!

Get to grips with a medieval drawbridge's key mechanisms



Lifting drum
Wooden and metal cylinders positioned in the roof of the gatehouse – when turned by the windlass – draw in the bridge's chains to raise it.

Chain
The bridge's chains extend from the far end of the bridge, through the gatehouse's exterior and on to the lifting drums. Each chain wraps around its drum as the bridge is lifted.

Bridge
The bridge itself is constructed out of wood and pivoted on a metal cylinder at the base of the gatehouse. Its underside is commonly reinforced with metal plate.

Moat
A water-filled moat or ditch is a common feature of medieval castles, with the drawbridge providing the only dry entry into the structure. Lifting the bridge prevents easy access.

Counterweights
Without counterweights, the hefty bridge would be too much for the windlass system. With them installed, this weight can be offset to a degree and they take a lot of the strain out of the operation.

Portcullis
A second barrier that sits behind the drawbridge is the portcullis. This metal and wood gate can be slid or dropped across the entrance to bar intruders.

Windlass
The key mechanical part of the system, the windlass – when operated by lever or rotary wheel – turns the lifting drums to draw in or let out the chains.

Pit
When the drawbridge is up, the counterweights drop into a pit in the gatehouse floor. When the bridge is down, the pit is covered with trapdoors.

© Alamy/Peters & Zabransky

DID YOU KNOW? *There are 20 quills laid out every day the US Supreme Court is in operation*

Flint weapons

How human tool and weapon manufacturing first began

Before metals were first extracted during the Bronze Age, tools and weapons were made out of stone. A fundamental material used in the Stone Age was a sedimentary rock known as flint. Strong and with sharp edges, flint is plentiful in chalk and limestone beds around the world, which made it ideal for the first primitive tools and weapons. The stone was first mined over a million years ago during the Paleolithic period, using an extraction method known as flintknapping. This would involve chipping away at the seam of rock until the desired shape of blade was created. Some of the earliest flint tools were hand axes, which were used to hunt animals, chop wood, dig and even start a fire. Early weapons were big and blunt while later arms were better crafted, polished and sharper. From these primitive beginnings would arise the first daggers, spears and arrowheads, becoming an integral part in Stone Age warfare, toolworking and hunting.

The age of stone

The eras in which flint was a major component

Paleolithic period

Approx 2.5 million years ago

Flint tools of this age were at their most primitive with only basic tools like hand axes made. This type of toolwork was used by Homo erectus as well as Homo Sapiens.

Mesolithic period

Approx 15,000 years ago

Tools became more sophisticated in this era, being used in carpentry to make the first structures. The first pottery was made in this period, in no small part due to this evolution.

Neolithic period

Approx 12,000 years ago

Emerging agriculture was the influence on the tools of this age with scythes made to harvest grain. Tools of this era also had a distinctive appearance due to increased polishing.

Breaking the sound barrier

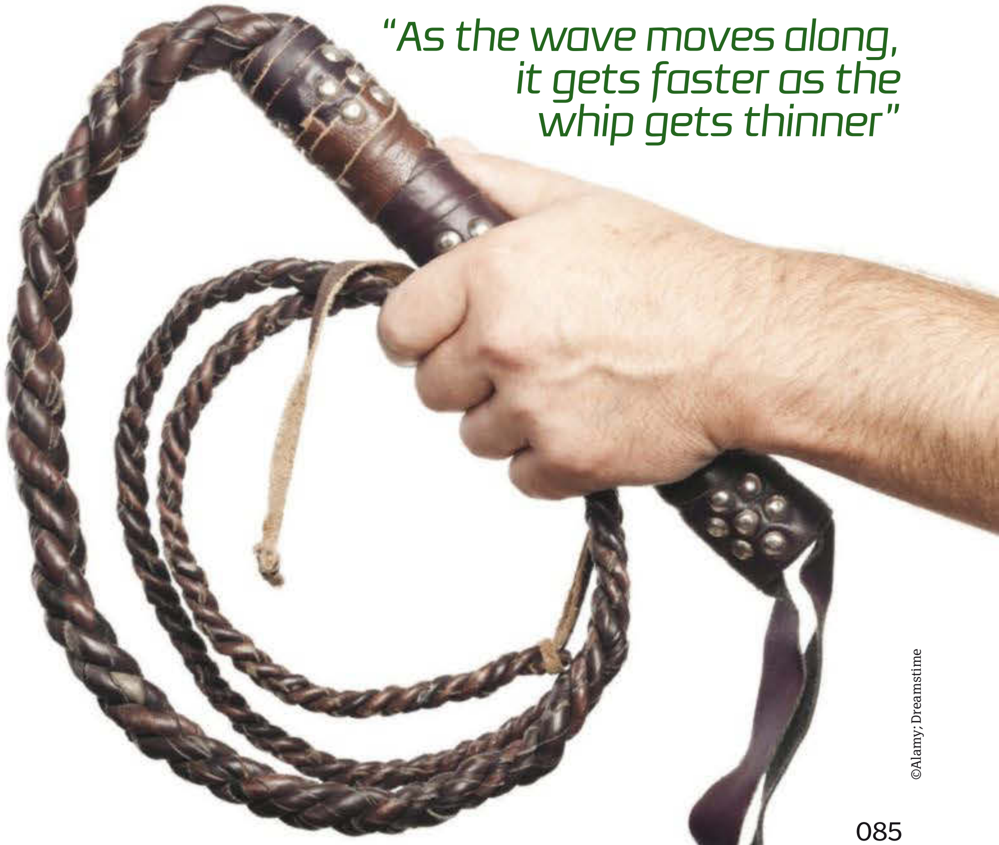
What was the first thing to go faster than sound?

The first time that magical speed of 1,225 kilometres (761 miles) per hour was breached dates back to the Ancient Egyptians. They are one of the first civilisations recorded as using a whip, which has been creating sonic booms for over 4,000 years.

Lifting a whip and bringing it down sharply causes a ripple to move down the length of the whip as it rises up then snaps back down. As the wave moves along, it gets faster as the whip gets thinner. This continues until it reaches the tip and the thinnest part of the whip. If you have done it right, by this point the wave is moving so fast that the tip breaks the sound barrier as it flicks up, creating that characteristic crack.

Incidentally, the first human to travel faster than sound was US Air Force Captain Chuck Yeager as he flew an X-1 plane at Mach 1 – the speed of sound – in 1947.

"As the wave moves along, it gets faster as the whip gets thinner"



©Alamy; Dreamstime

Brutal battering rams

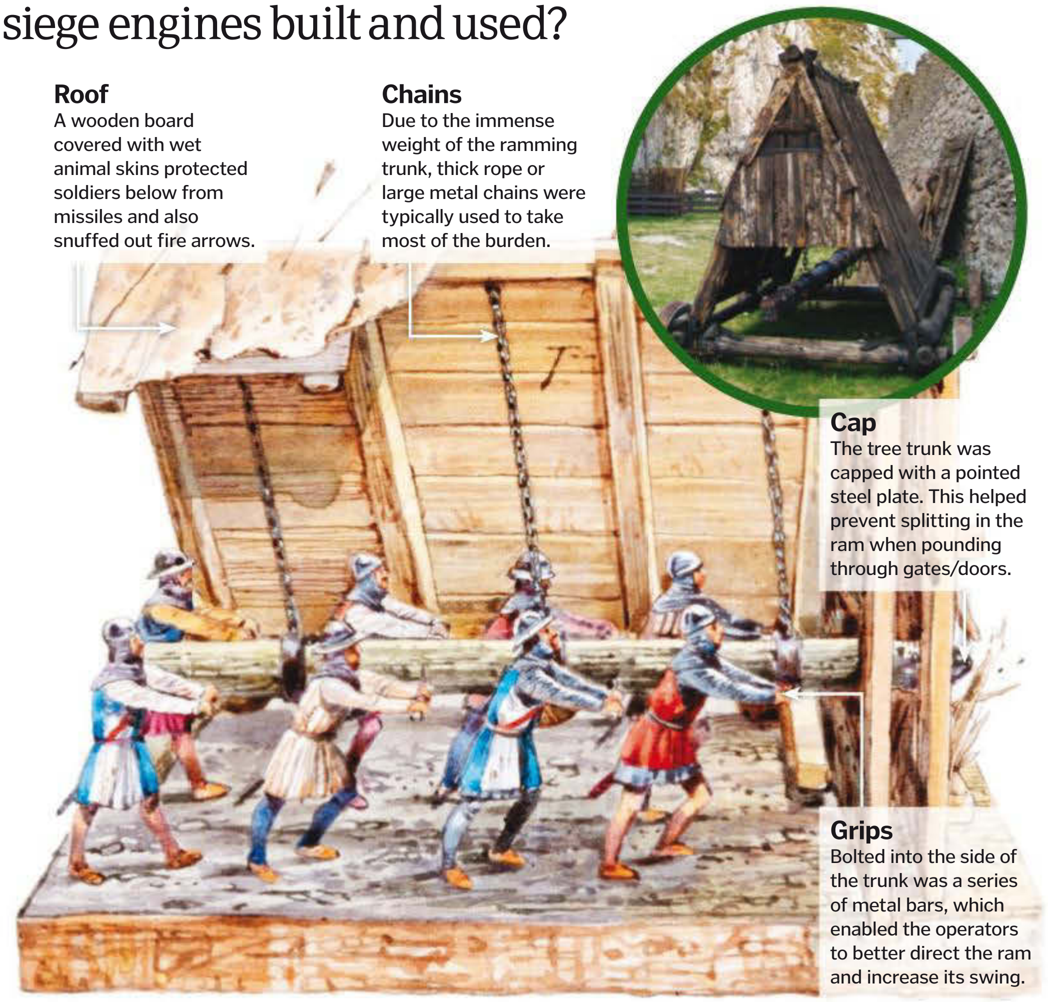
How were these powerful siege engines built and used?

Battering rams were one of the most common pieces of siege equipment from antiquity right through to the Middle Ages, often granting offensive forces access to an enemy's fortified stronghold or city.

A typical battering ram consisted of a rectangular wheeled frame from which a large tree trunk was slung via ropes or chains. The suspended trunk would then be rocked backwards and forwards within the frame until it swung with great force. By placing an obstacle – such as a wooden gate – in the ram's path, it could transfer a vast amount of energy into the target, often shattering the defence.

However, for a ram to get up to speed, a team of soldiers was required to first place it in position and also control its swinging – both of which are difficult when under fire by ranged weapons. To counter this, battering rams often featured triangular wooden coverings stretched with wet animal hides. This shielding not only protected the soldiers from direct missile strikes but also the risk of fire, with the hides extinguishing any flaming arrows.

The age of the battering ram came to a close largely due to the proliferation of gunpowder and explosives in the late-Middle Ages, with army sappers using these incendiary devices to bring down gates and walls much faster.



Roof
A wooden board covered with wet animal skins protected soldiers below from missiles and also snuffed out fire arrows.

Chains
Due to the immense weight of the ramming trunk, thick rope or large metal chains were typically used to take most of the burden.

Cap
The tree trunk was capped with a pointed steel plate. This helped prevent splitting in the ram when pounding through gates/doors.

Grips
Bolted into the side of the trunk was a series of metal bars, which enabled the operators to better direct the ram and increase its swing.

What other weapons were used in siege warfare?

Trebuchet
One of the most useful siege weapons ever to be created, the catapult-style trebuchet allowed an army to bombard a city's walls and interior buildings with huge stones, flaming balls of earth and even dead animals (the latter spreading disease and panic throughout the inhabitants). On the downside, trebuchets required a large team to operate effectively.

Ballista
A large missile-throwing weapon, the ballista was an excellent choice when you wanted to disrupt infantry columns. Developed first by the Ancient Greeks, the ballista worked via torsion springs, with huge wooden spikes propelled at great speed when released over large distances. The ballista would be scaled down over the centuries until eventually it could be handheld.

Tower
A simple yet devastatingly effective siege weapon if used correctly, the tower was literally a mobile wooden turret on wheels that enabled troops to scale enemy walls in relative safety. After climbing up through the shielded internal cavity, soldiers would then be released with the dropping of a small drawbridge, enabling them to charge over enemy battlements.

© Thinkstock

DID YOU KNOW? *The Zulu are still the largest ethnic group in South Africa and Zulu is a widely spoken language in the country*

Secrets of the Zulu warriors

How did the Zulus become South Africa's most feared fighting force?

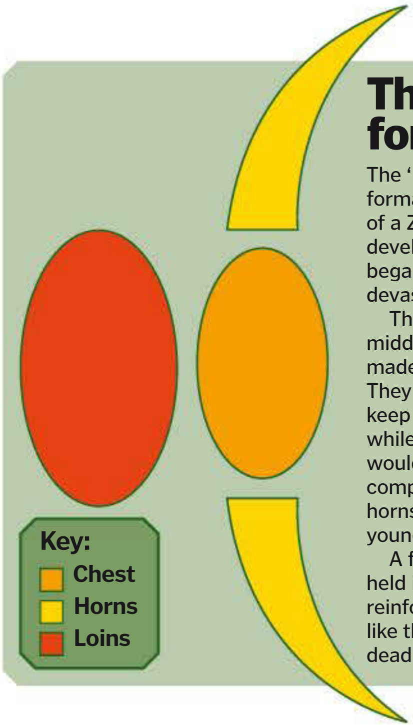
From 1816 to 1879 the Zulu Kingdom became one of the most powerful tribal societies in what is now South Africa. Only the arrival of the British Empire finally ended their expansion across the KwaZulu-Natal region in the bloody Anglo-Zulu War of 1879, after which the Zulu Kingdom became subject to the authority of British Queen Victoria.

Born around 1787, Shaka Zulu, the illegitimate son of chieftain Senzangakhona, had a lot to prove, and he did so the hard way. Taking control after his father's death, Shaka curbed the power of the witch doctors and transformed the army with reforms. Among those was a policy of absorbing defeated tribes into his kingdom and promoting men based on ability rather than family ties.

Zulu warriors also gained new weapons, including the short, stabbing iklwa spear (the name gruesomely said to be the sound made when pulled from a corpse), and revised tactics. Zulu warriors were trained harshly too, forced to throw away their sandals so they could run faster – those who complained were simply killed – they reportedly jogged up to 80 kilometres (50 miles) in a day, with children as young as six running after them with food and other vital supplies.

By Shaka's death in 1828, the Zulu Kingdom had expanded to cover an incredible 29,800 square kilometres (11,500 square miles) of land and ruled over an estimated 250,000 people.

The Zulu's killer formation



Key:
🟧 Chest
🟨 Horns
🟥 Loins

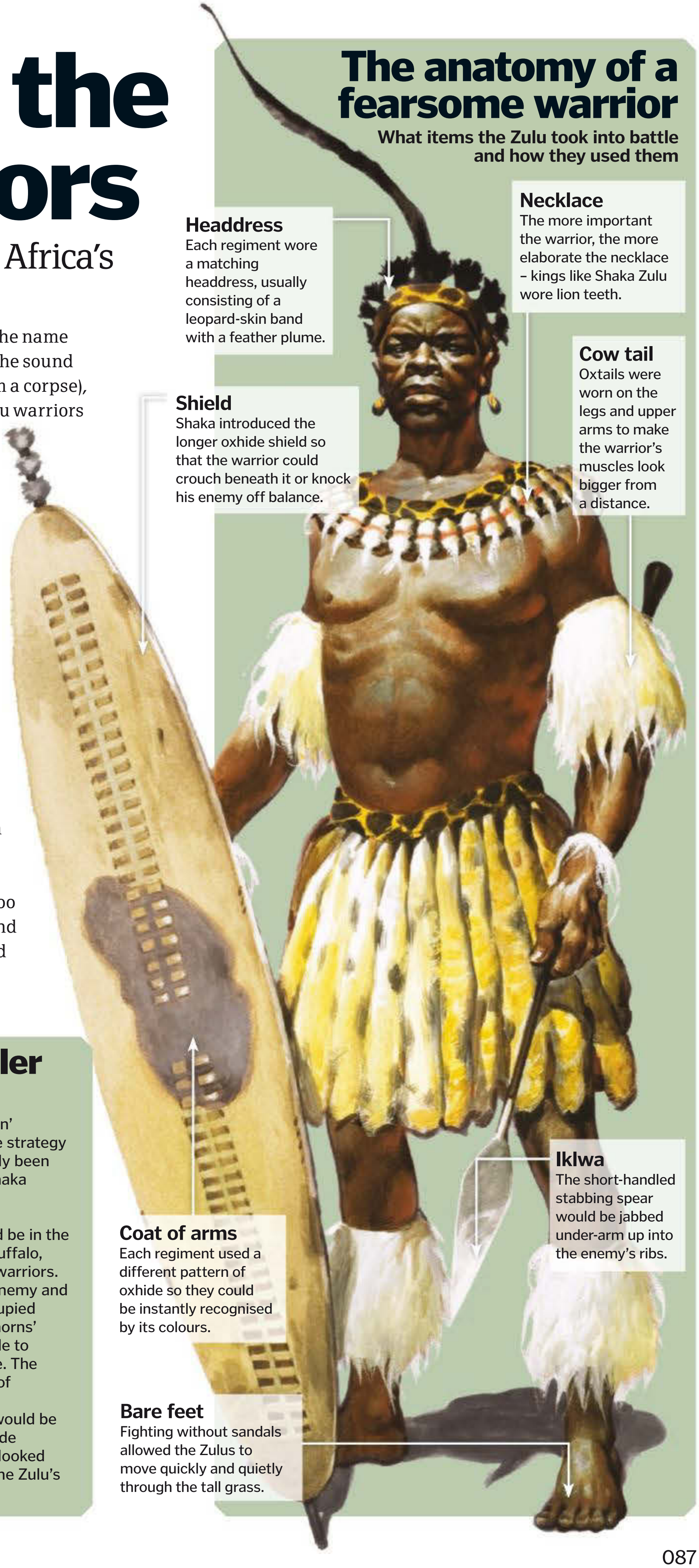
The 'Buffalo horn' or 'bull-horn' formation was the core battle strategy of a Zulu army. It had originally been developed for hunting, but Shaka began to use it in battle, with devastating success.

The bulk of the force would be in the middle as the 'chest' of the buffalo, made up of battle-hardened warriors. They would charge into the enemy and keep them well and truly occupied while two smaller forces of 'horns' would circle around either side to completely surround their foe. The horns were often comprised of younger and faster warriors.

A fourth force, the 'loins', would be held in reserve ready to provide reinforcements if the enemy looked like they might break out of the Zulu's deadly trap.

The anatomy of a fearsome warrior

What items the Zulu took into battle and how they used them



Headdress
Each regiment wore a matching headdress, usually consisting of a leopard-skin band with a feather plume.

Necklace
The more important the warrior, the more elaborate the necklace – kings like Shaka Zulu wore lion teeth.

Shield
Shaka introduced the longer oxhide shield so that the warrior could crouch beneath it or knock his enemy off balance.

Cow tail
Oxtails were worn on the legs and upper arms to make the warrior's muscles look bigger from a distance.

Iklwa
The short-handled stabbing spear would be jabbed under-arm up into the enemy's ribs.

Coat of arms
Each regiment used a different pattern of oxhide so they could be instantly recognised by its colours.

Bare feet
Fighting without sandals allowed the Zulus to move quickly and quietly through the tall grass.

© Getty

Meet the musketeers

One of the most popular military units for centuries, musketeers fought in battles and protected esteemed rulers all the way from France to India

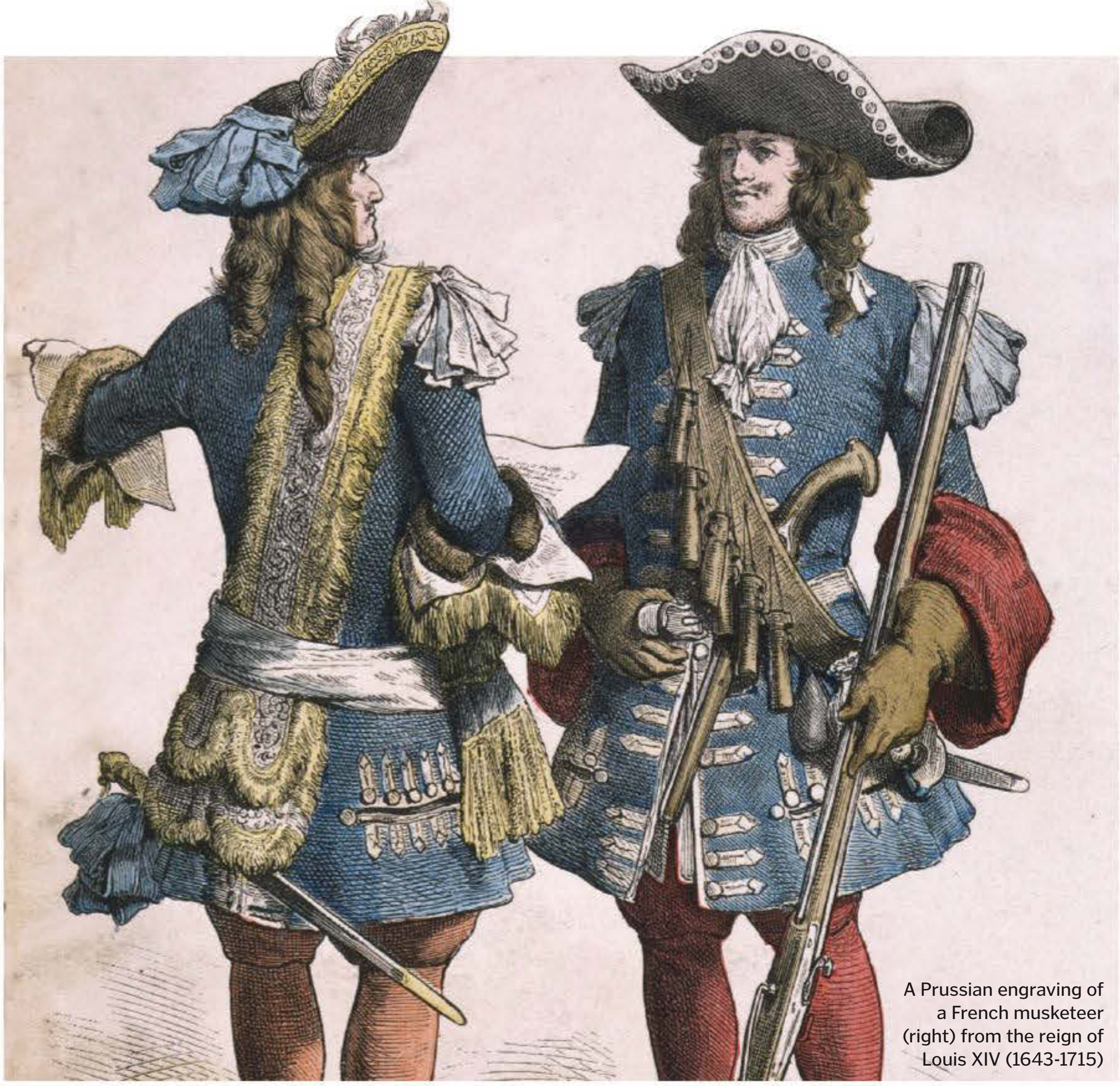
Musketeers were an early form of soldier who were armed with muskets. They acted as a bridge unit between traditional infantry – which fought on foot and typically hand-to-hand with swords and other melee weapons – and dragoons, a type of light cavalry armed with long-ranged weapons. This granted them a level of versatility and flexibility most prized on the battlefield, with musketeer units typically reserved for the protection of nobility or, in many Western nations, royalty.

While musketeers as a unit are older (see 'Musketeer origins' boxout for details), they didn't emerge in Europe until the 16th century, with the concept only really taking off on a large scale in the early-17th century.

While this particular era was dominated by the French musketeers of the Maison du Roi (the Royal Household) – upon which the fictional musketeers of Alexandre Dumas' *The Three Musketeers* are based – countries like Spain, Britain, Russia, Sweden, Poland and even India each developed their own musketeer units in this period and used them on the battlefield frequently.

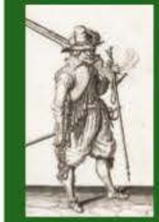
Musketeers as a common military unit were largely phased out by the middle of the 19th century, with a number of new developments in firearms rendering the musket obsolete. With the introduction of the rifle – which could shoot both farther and much faster than the musket – the rifleman unit would emerge, negating the need for the greater speed afforded by the mounted musketeer.

This, combined with the decline of many dynasties throughout Europe – notably the Ancien Régime of France during the French Revolution – saw all musketeer units permanently disbanded.



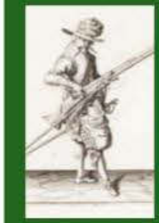
A Prussian engraving of a French musketeer (right) from the reign of Louis XIV (1643-1715)

How to fire a musket step-by-step



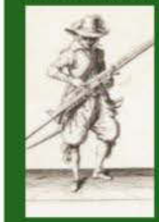
1 Carry

While marching to position the musket should be carried over the shoulder, with the firing rest secured in your off-hand.



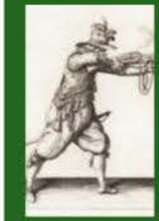
2 Firing prep

When firing is ordered, the musket is filled with priming powder, charge and ball, with the weapon held in a diagonal orientation.



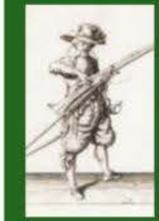
3 Insert fuse

The match fuse should then be cocked in the matchlock and blown on, ensuring at all times that the match doesn't extinguish.



4 Shoot

Draw up the musket while simultaneously securing the firing rest. Slot the musket in the rest's support brace, aim and fire.



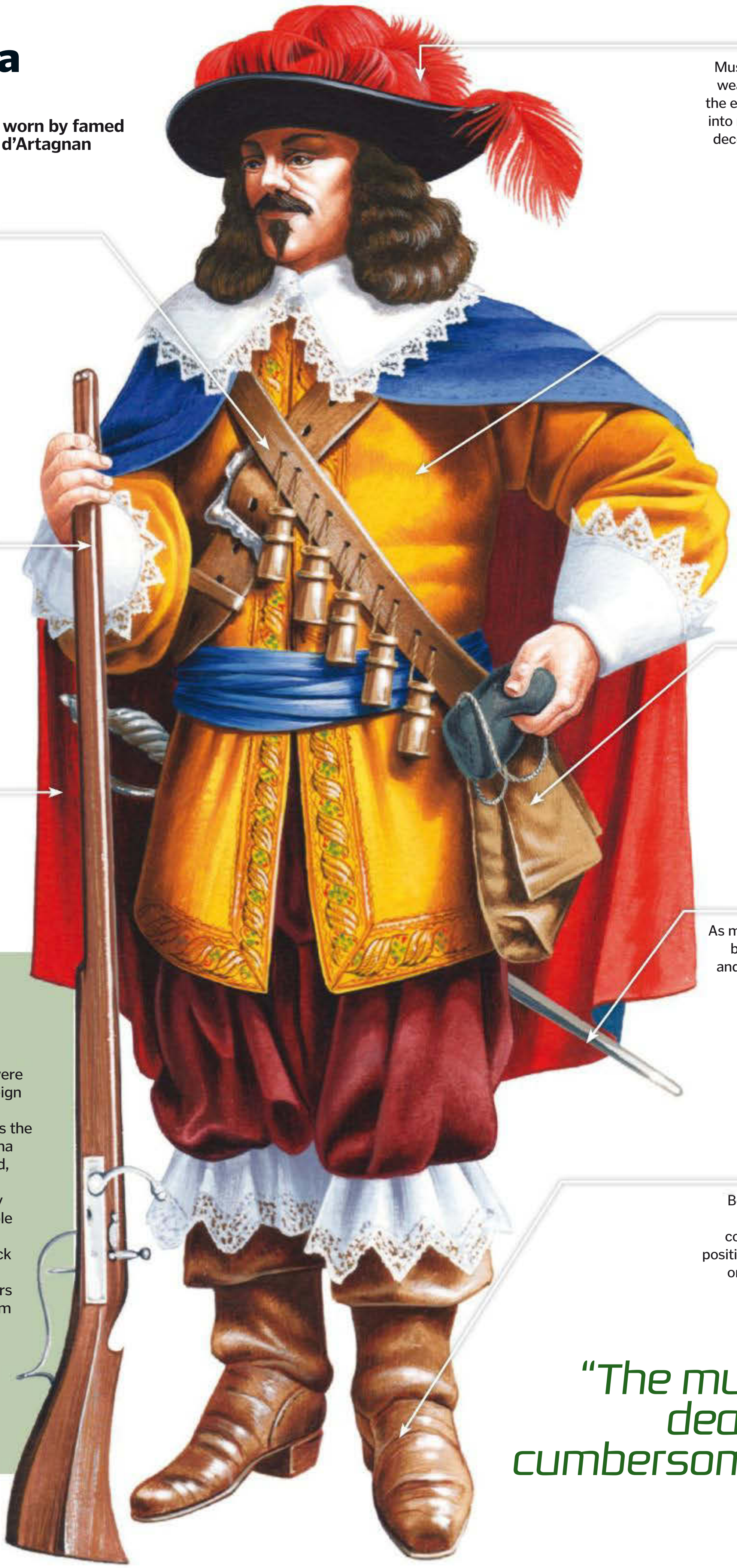
5 Withdraw

Bring the musket off its rest, draw it down to your side, then take the fuse off the musket and await further instructions from superiors.

DID YOU KNOW? *Musketeers of the Guard fought both on foot and on horseback*

Uniform of a musketeer

Check out the essential kit worn by famed musketeer captain, Comte d'Artagnan



Hat
Musketeers started off in the West wearing simply ornate hats, but by the early-19th century these evolved into metal helmets. They did remain decorative though, often with large feathered plumes attached.

Bandolier
Bandoliers (a pocketed belt) and ammunition pouches/bags were a common accessory for musketeers, so they were always well supplied on the battlefield. These belts were strapped around the waist or chest.

Tunic
Considerably more elaborate than standard infantry, musketeer tunics and – in later periods – cuirasses, favoured manoeuvrability over armoured protection.

Musket
The musketeer's primary weapon, the musket was deadly albeit cumbersome to use. Its slow reload rate restricted use to four shots per minute at best.

Holdall
As musketeers were on the road during much of their military service, each carried their own holdall to store food and personal belongings.

Cape
A feature associated more with earlier iterations of musketeers, the cape offered some protection from the elements while travelling.

Sword
As musketeers were trained to fight both on horseback like dragoons and on foot like infantry, they were also equipped with a sword for hand-to-hand engagements.

Boots
Boots were an important part of the musketeer's uniform, both communicating their prestigious position and providing good support on the ground and on horseback (some had spurs attached).

Musketeer origins

Unlike the musketeers of the Maison du Roi – the Royal Household of France – who were founded in 1622 during the reign of Louis XIII, musketeers had already been operating across the other side of the world in China since the 14th century. Indeed, through the Ming Dynasty (1368-1644) no national army was complete without multiple musketeer divisions, with soldiers armed with matchlock muskets. Surviving texts indicate that these musketeers fired in lines and typically from a kneeling position. This development of the concept of musketeers in China stemmed from their invention and mastery of gunpowder, with the musket revolutionising traditional forms of combat.

> "The musket was deadly, albeit cumbersome to use"

© Alamy; Ian Jackson/The Art Agency

Battle of Agincourt

The most famous conflict of the Hundred Years' War, the Battle of Agincourt was one of the most bloody and brutal in history

The Battle of Agincourt is one of Europe's most famous battles, echoing down the centuries in historical record, song and even dramatic re-enactment on stage and film. The battle itself was part of the Hundred Years' War, a series of conflicts that actually waged for over a century (1337-1453) between the Kingdoms of England and France for control of the French throne.

The two contenders for the throne were the House of Valois, a noble French family from the Capetian dynasty that had claimed the throne under Salic Law, and the House of Plantagenet's Angevin family, who contested the claim due to the ancestral marriage of Edward II of England to Isabella of France. These contested claims led to a number of brutal battles throughout the 14th and 15th centuries, which came to a head in the Battle of Agincourt, a horrific battle fought between King Henry V and King Charles VI on 25 October 1415.

The battle itself was a major English victory against a numerically superior French army – see 'Agincourt battle map' for a comprehensive rundown – that rested on a series of tactical mistakes by the French, commanded by Constable Charles d'Albret, and a series of tactical masterstrokes by King Henry V. Indeed, Agincourt has gone down in French history as one of their most disastrous defeats for the French, with around 8,000 French troops killed and hundreds of others wounded or taken prisoner. In contrast, the English losses were in the low hundreds.

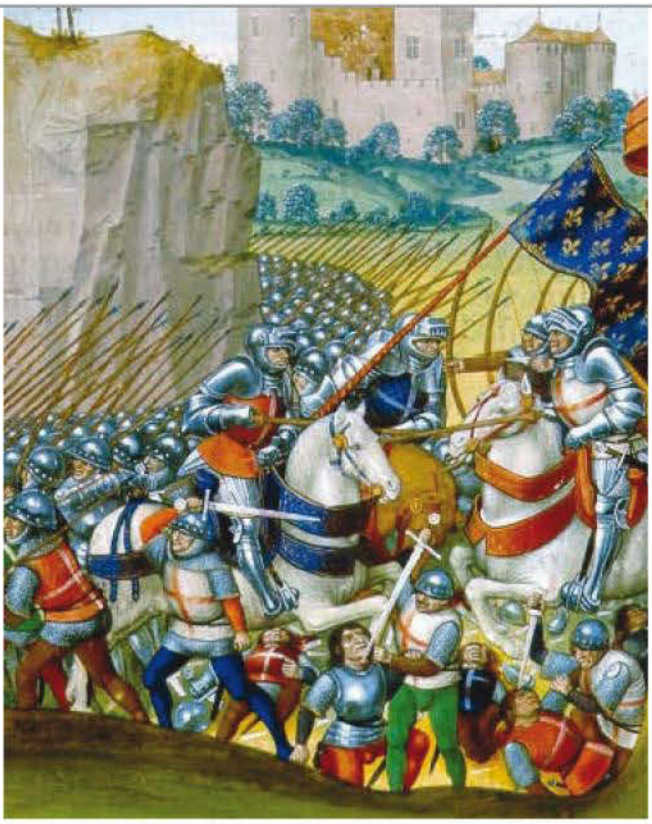
Interestingly, however, despite the conflict being such an obvious and celebrated English victory, the battle is remembered today more for its vivid representation of the polarised views and consequences that war in general generates (for William Shakespeare's take on this, see 'The turning of the tide' boxout over the page). There are a number of reasons why opinions about it are so divided.

The first is due to the sheer magnitude of the casualties and the way in which they died. Records indicate men were decapitated, cleaved in two, had their bones shattered, were trampled to death, suffocated and had their major organs shredded by arrows. The battle was, without doubt, one of the bloodiest meat-grinders ever witnessed.

The second, and arguably more poignant reason, is despite Henry winning the day at Agincourt and later being named regent and heir to the French throne – a goal he had chased all his adult life – he died before he could be crowned and his successors proceeded to quickly lose both the throne and much of the territory in mainland France that he had won through his campaign.

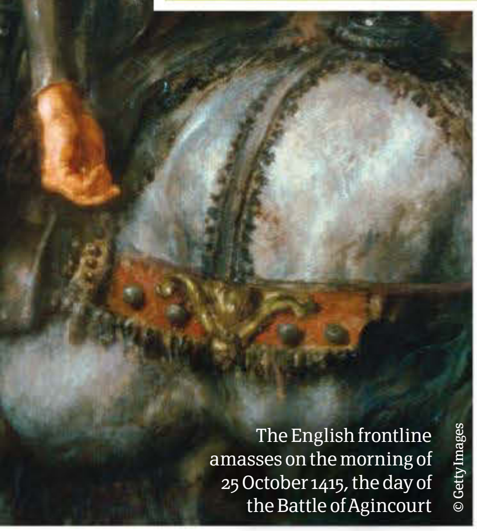
Lastly, despite Henry's actions being accepted as justified at the time by both French and English chroniclers, his actions were heavily criticised both morally and ethically in later times. Arguments not only

DID YOU KNOW? *Actor Kenneth Branagh played Henry V in the 1989 film adaptation of Shakespeare's play*



Agincourt today. Despite almost 600 years having passed since the famous battle, the terrain is still ploughed fields, a factor that greatly contributed to the English victory

© Alamy



The English frontline amasses on the morning of 25 October 1415, the day of the Battle of Agincourt

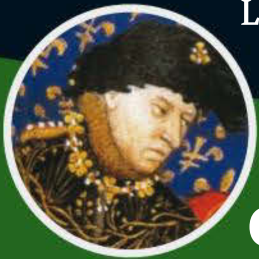
© Getty Images

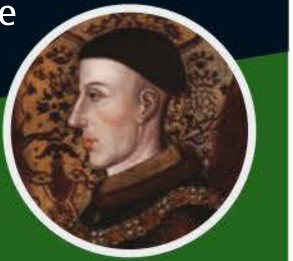
contested his right to invade, but also his decision to execute all but a handful of the French prisoners taken at the battle, which while numbers are unclear, probably approached, or even exceeded, a thousand men. Indeed, the French losses at Agincourt largely obliterated their aristocracy, with hundreds of noblemen (including three dukes, eight counts and one viscount), knights and even an archbishop killed in the fighting.

In this feature we break down the main events of the battle itself, and analyse the surrounding context, highlighting the key players and exploring the ramifications that Agincourt had on the economic, social and political spheres of Europe in the Late Middle Ages and beyond.

A clash of kings

Let's pit the warring monarchs of France and England head-to-head





King Charles VI		King Henry V
46	**Age (at Agincourt)**	29
1368	**Born**	1386
House of Valois	**Lineage**	House of Lancaster
4	**Children**	1
Catholic	**Religion**	Catholic
1380-1422	**Reign**	1413-1422
Charles V	**Predecessor**	Henry IV
1422 in Paris	**Death**	1422 in Bois de Vincennes

Background: Nicknamed both Charles the Beloved and Charles the Mad, King Charles VI ruled France for 42 years despite frequently succumbing to bouts of mental illness (see 'The mad king' boxout). He was the son of King Charles V and Joan of Bourbon. His reign was characterised by ceding territory to foreign powers and the creation of power struggles within the French aristocracy.

Background: The last of the great warrior kings of the Middle Ages, King Henry V ruled England for nine years and in that time managed to expand its empire significantly. His reign was characterised by military conquest and solid political and financial support from the English parliament and the country's barons. However, his reign did leave England in poor shape financially.

Agincourt battle map

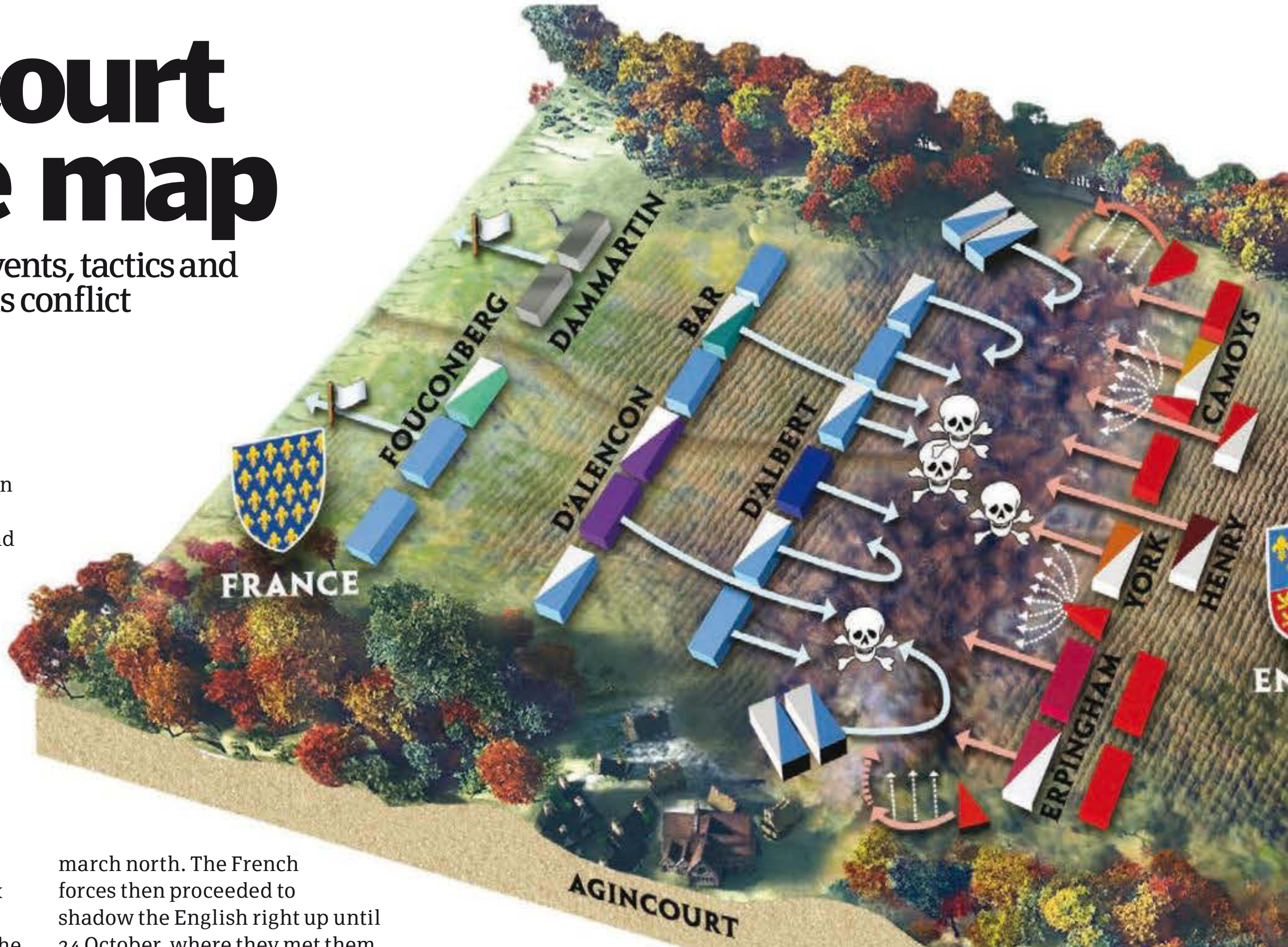
Discover the main events, tactics and terrain of this famous conflict

Contextually, the two sides approached the Battle of Agincourt from completely different directions – both literally and metaphorically. Henry had been campaigning in France since 13 August 1415, which had seen him besiege and take the port city of Harfleur and cover hundreds of miles through Normandy. As a result, the English forces were exhausted from fighting and marching, as well as suffering from severe food shortages, and disease was rife.

In contrast, the French had assembled a large army during Henry's taking of Harfleur at Rouen and then moved to block Henry's crossing of the River Somme on his march north to the English stronghold of Calais. The French forces were much fresher, substantial in number – with many nobles and soldiers alike amassed – and better equipped. All these factors led them to believe, quite understandably, that if a battle did happen, they would win decisively.

After being initially prevented from crossing the River Somme, Henry finally managed to cross it south of Péronne at Béthencourt and Voyennes and resumed his march north. The French forces then proceeded to shadow the English right up until 24 October, where they met them at Agincourt. The French, however, did not engage the English immediately, as they were expecting additional troops to arrive to support them. As such, the first day passed without incident, setting up 25 October as one of the most famous days in European military history.

For a blow-by-blow account of the battle, read through our chronological guide of the main events, which can be followed directly on the battle map.



Unit guide

French

Standard: Arms of the Kingdom of France
Men (estimate): 12,000-36,000
Archers and infantry: Blue 🟦
Cavalry: Blue and white 🟦 ☐
Constable Charles d'Albret: Dark blue 🟦
Duke of Alençon: Purple 🟪
Duke of Bar: Turquoise 🟩
Count Fauconberg: Cyan 🟦
Count Dammartin: Silver ⬜

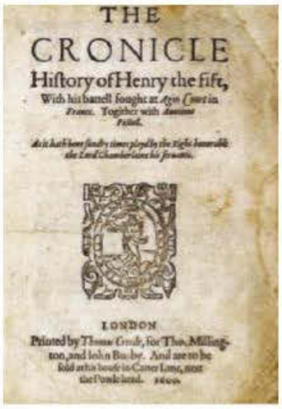
English

Standard: Royal Arms of England
Men (estimate): 6,000-9,000
Archers: Red triangle ▲
Infantry: Pink 🟥
Cavalry: Red and white 🟥 ☐
King Henry V: Maroon 🟫
Duke of York: Orange 🟧
Sir Thomas Erpingham: Green 🟩
Baron Thomas de Camoys: Yellow 🟨

The turning of the tide

Shakespeare's dramatic re-enactment of the Battle of Agincourt in Henry V sends out some mixed messages

William Shakespeare's play *Henry V* (c. 1599) is interesting in its ambiguously polarised views on the battle, Henry himself, and war in general. On one hand, Shakespeare appears to praise military conquest and justify Henry's campaign – most notably in his famous St Crispin's Day speech, where Henry rallies his men. On the other hand, the play doesn't shy away from detailing the horrors of war and even closes with a reminder that, while Henry's victory won him the French throne, in the long term his son lost it and the battle was, historically, largely inconsequential.


THE
CRONICLE
Hiſtory of Henry the fift,
With his battell fought at *Agin Court* in
France. Together with *Auntient*
Pistoll.

As it hath bene ſundry times playd by the Right honorable
the Lord Chamberlaine his ſeruants.

LONDON
Printed by *Thomas Creede*, for Tho. Milling-
ton, and Iohn Busby. And are to be
ſold at his house in Carter Lane, next
the Powle head. 1600.

Step-by-step event guide

How did Henry V lead the English to victory?

1 Henry advances towards the French frontline, ordering his archers to uproot their defensive spear wall and replace it farther up the battlefield. This catches the French forces off-guard and they fail to charge before the spear wall is reinstated. English longbowmen in the central frontline begin bombarding the French with arrows.

2 While the French frontline try to quickly organise themselves for a frontal charge, Henry orders his flanking squads of longbowmen to move up the battlefield within the trees to the right and left, advancing to a point where they can fire from either flank into the centre of the French troops. Like the frontline archers, they set up spear walls.

3 Constable D'Albret orders the French frontline to charge at the English frontline. They are met by multiple waves of arrows, which decimate large

DID YOU KNOW? *As well as being famed for his military prowess, Henry V was also considered a shrewd political diplomat*

Where it went wrong for the French

Drawing on the lessons of military history, we weigh up where Charles d'Albret's strategy foundered, and how the French might have won the battle

Key to Henry's victory was his good use of tactical positioning and Constable D'Albret's poor use of it. Indeed, with D'Albret's bigger and fresher force, he arguably should have won the battle if he had made a few key adjustments.

First, if D'Albret had engaged Henry's forces on a more open terrain, he would have been able to better utilise his large selection of cavalry, which during the skirmish could not outflank the English forces and so were unfortunately forced to charge head-on.

Second, D'Albret totally underestimated the damage that could be inflicted by the English longbowmen, who were the best archers in the world at the time. As such, French cavalry and infantry alike were continuously bombarded from the front and sides by Henry's well-placed units, severely decimating their troops before they even reached the English frontline. Once again, a more open terrain could have avoided this.

Third, and last, D'Albret's forces – notably the French army's noble knights – were outfitted in heavy armour. While such gear provided a greater degree of protection in hand-to-hand combat, it severely limited their movement and agility, something that would become fatal on the busy, muddy central battlefield. Indeed, reports indicate that the battlefield became so cramped and sodden that when knights were knocked down they struggled to even stand back up again, let alone efficiently engage the lighter-armoured, and so more agile, English troops.

TRAMECOURT
NGLAND
MAISCONCEUES

numbers of their cavalry and infantry as they cover the central battlefield. The English archers on each flank also begin firing, hitting the French frontline from both sides.

4 D'Albret and limited numbers of the French frontline reach the English spear wall and begin to engage them in hand-to-hand combat, pushing it backwards. The longbowmen retreat and Henry orders his infantry to advance and meet the French face-to-face.

5 Fierce, close-quarters fighting begins upon the sodden, muddy ploughed terrain at the centre of the battlefield. The combination of the dense mud and heavy armour worn by the French knights leads to thousands of them getting severely bogged down and exhausted, with the lighter-armoured English forces able to operate much more effectively.

6 D'Albret is suddenly killed in the melee, falling into the mud. Meanwhile, the French second line advances into the centre of the battlefield congesting it further. At this point the two side flanks of English archers abandon their ranged weapons and rush into the French second line from both the right and left.

7 The Duke of York is killed by a blow to the body and proceeds to get lost amid the sea of fighting soldiers. In addition, Henry's brother – Humphrey, the Duke of Gloucester – is wounded by a blow to the groin. Henry quickly moves to his position and defends him with his personal retinue – he succeeds but in the process receives a blow to the head that removes part of his crown.

8 The Duke of Bar is killed as his forces get depleted by the encircling English. Upon seeing the disaster that is unfolding before his eyes, the Duke of Alençon attempts to reach the English to submit a surrender notice, however he is killed by a blow to the head before it can be delivered.

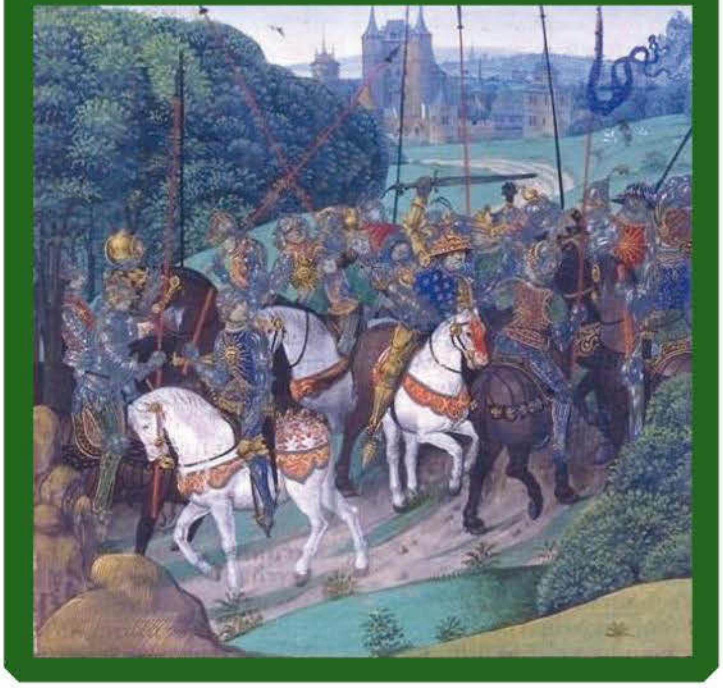
9 The third line of French forces hovers on the outskirts of the battle, unsure whether to fight or not. Henry perceives they will and, due to the large number of unrestrained French prisoners from the first and second waves, orders all but the most high-ranking to be executed to prevent them from rearming en masse and overrunning the exhausted English.

10 Upon seeing the vast losses and executions, the French third line, led by the Counts Fauconberg and Dammartin, retreat to the rear, fleeing the battlefield. Henry wins the battle and orders a count of the dead, which reveals roughly 8,000 French troops had died compared to the English's 450.

The mad king

King Charles VI wasn't at Agincourt as his court considered him unstable, but was he?

Charles VI's reign was blighted by an apparent mental illness, which manifested itself in a series of conditions ranging from him believing he was made of glass to outright paranoia and violent episodes. One of the most notable of these episodes was during a march to Brittany from Paris to punish what Charles VI perceived to be a would-be assassin. After being warned by a passing leper that he should turn back as he was betrayed, he reportedly suddenly shouted, "Forward against the traitors! They wish to deliver me to the enemy!" and proceeded to hack down and kill several of his personal bodyguards (see picture below). After finally being dragged from his horse, Charles fell into a coma. As such, and especially towards the end of his reign, he was largely confined to his residence in Paris and – as a direct consequence – did not lead his forces at the Battle of Agincourt.



Jousting explained

High-speed, brutal and theatrical; it's easy to see why this martial sport was so popular in the Middle Ages

Jousting was a martial sporting event undertaken between two horsemen using lances, each aiming to strike the other and unhorse him. It worked either as a single event or as part of a larger tournament, the latter involving other athletic disciplines such as hand-to-hand combat.The joust itself, however, worked on a point-scoring system, with each true blow struck on the opponent generating a number of points for the striker, the total depending on where the blow landed. So, if a rider hit his opponent on the helmet he was awarded two points, while if he struck them on the breastplate only a single point would be awarded. If a rider unhorsed his opponent with a strike then he was awarded three points and the match was considered over. Importantly, however, only true blows generated points, with a true blow consisting of the lance shattering on impact. Glancing blows, low blows and any strike that did not shatter the lance were not counted.

For each joust both horsemen were equipped with a trio of lances, to be used over a series of three charges. All lances were measured before each joust to ensure they were of equal length and therefore no reach advantage could be sought. In addition, strict rules governed each meeting, with only the horseman's squire (assistant) allowed to hand him new lances or help him in the event of an unhorsing. As part of these rules, it was also mandatory that any knight competing own the horse and armour he was using, as in the event that they were unhorsed, their opponent could demand both as a victory trophy. Of course, all these rules came behind the first and most important, which stated that only noblemen could compete.

If the joust was held as part of a larger competition, the other key event was the hand-to-hand combat match. This worked along a similar set of rules to the joust proper, with the first knight to land three blows on his opponent the victor. Which weapons and styles were allowed were dictated before the tournament.

Historically, jousting emerged out of the High Middle Ages (1000-1300) and was based on the military use of the lance by heavy cavalry. Up until the 17th century, jousting gradually evolved

DID YOU KNOW? *Jousting was phased out in France after King Henry II was mortally wounded in a tournament in 1559*

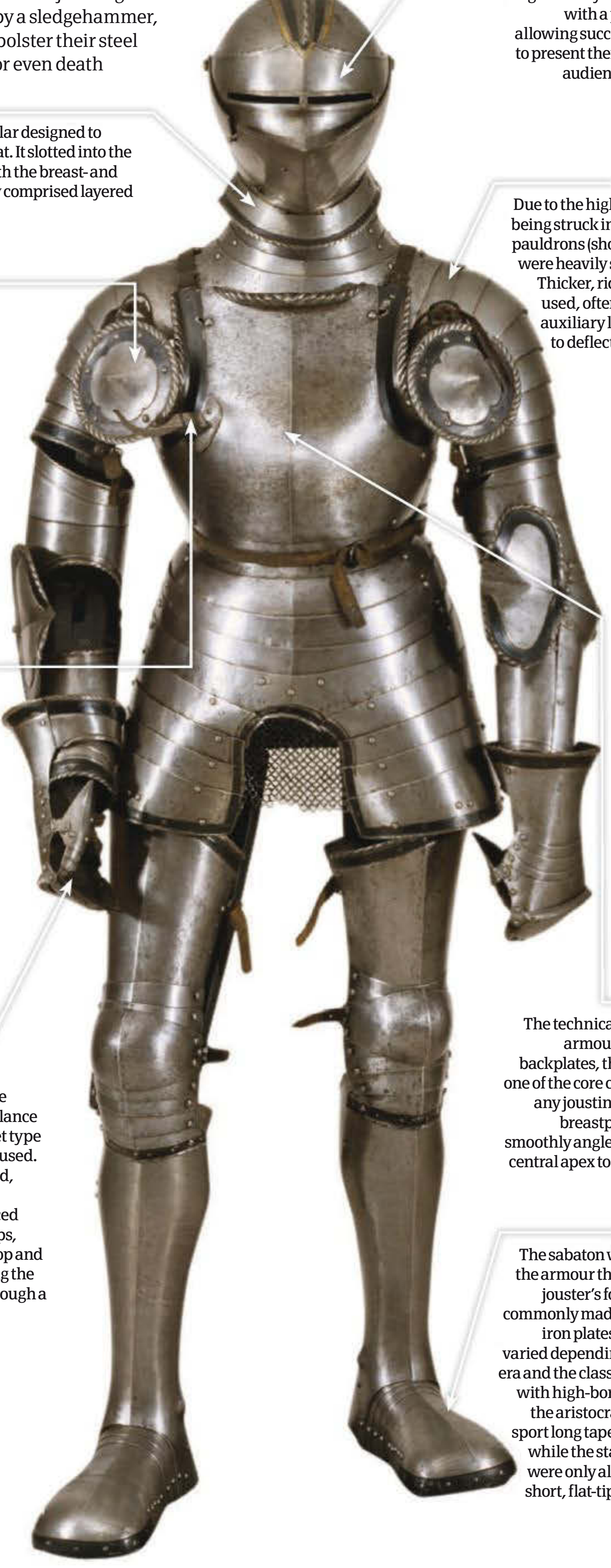
from a blood sport into the sporting form of chivalry for which it is now remembered. By the time of Queen Elizabeth I's reign (1558-1603), jousting had been heavily romanticised and was known more as a form of entertainment, rather than proof of military prowess.

Interestingly, today jousting is seeing something of a renaissance, with dedicated jousting clubs organising competitions and medieval re-enactment events held worldwide.

> *"Only true blows generated points in competitive jousts, with a true blow consisting of the lance shattering on impact"*

Jousting armour breakdown

Being hit with a lance while jousting was akin to being struck by a sledgehammer, requiring knights to bolster their steel plate to avoid injury or even death



Gorget
The gorget was a steel collar designed to protect the knight's throat. It slotted into the suit of armour underneath the breast- and backplates, and typically comprised layered and angled steel plates.

Besagew
Due to reduced necessity of movement while charging in horseback jousts, knights would often equip besagews (small circular shields) to their armour. These were designed to provide extra protection at joints – such as the armpit – where gaps in the plate could be exploited.

Lancer
A unique adaptation to standard plate armour was a lance holder, which was positioned beneath the right-arm pauldron. The steel hook was welded to the breastplate and helped support the lance while charging, allowing for a greater strike accuracy.

Gauntlet
Jousting gauntlets were designed to maximise the combatant's grip of their lance and, as such, Almain rivet type designs were commonly used. These consisted of layered, overlapping steel plates augmented with reinforced knuckle and fingertip caps, which covered only the top and sides of the hands, leaving the underside free to grip through a leather/fabric glove.

Helmet
Due to bonus points being awarded for a head strike, jousting helmets were heavily modified to add more protection. Armets and close helms were popular, as – aside from being sharply angled – they were equipped with a pivoting visor, allowing successful knights to present themselves to the audience post-battle.

Pauldron
Due to the high likelihood of being struck in the shoulder, pauldrons (shoulder guards) were heavily strengthened. Thicker, ridged steel was used, often with a fluted auxiliary layer designed to deflect lance strikes.

Cuirass
The technical name for the armour's breast- and backplates, the cuirass was one of the core components to any jousting armour. The breastplate was often smoothly angled away from a central apex to deflect blows.

Sabaton
The sabaton was the part of the armour that covered the jouster's foot. They were commonly made from riveted iron plates. Their design varied depending both on the era and the class of the jouster, with high-born members of the aristocracy allowed to sport long tapered sabatons, while the standard gentry were only allowed to wear short, flat-tipped varieties.

The first telephone

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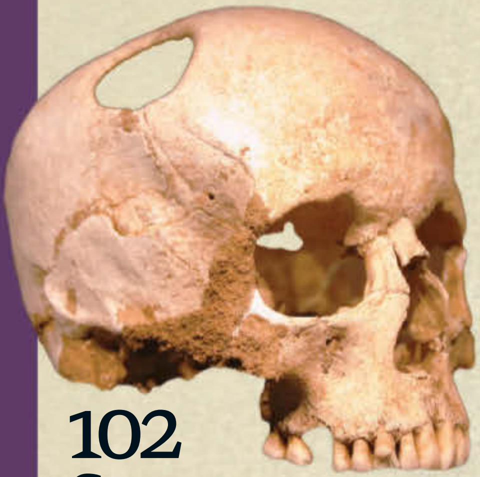

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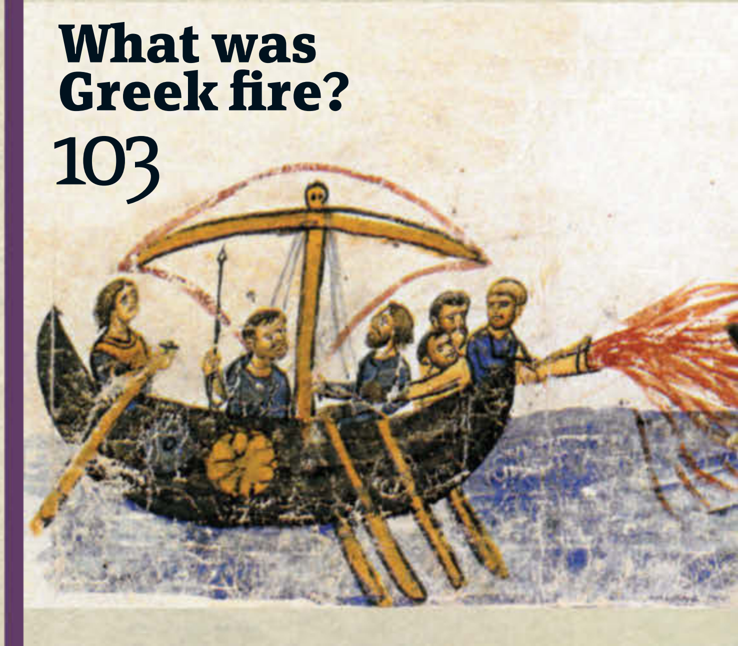

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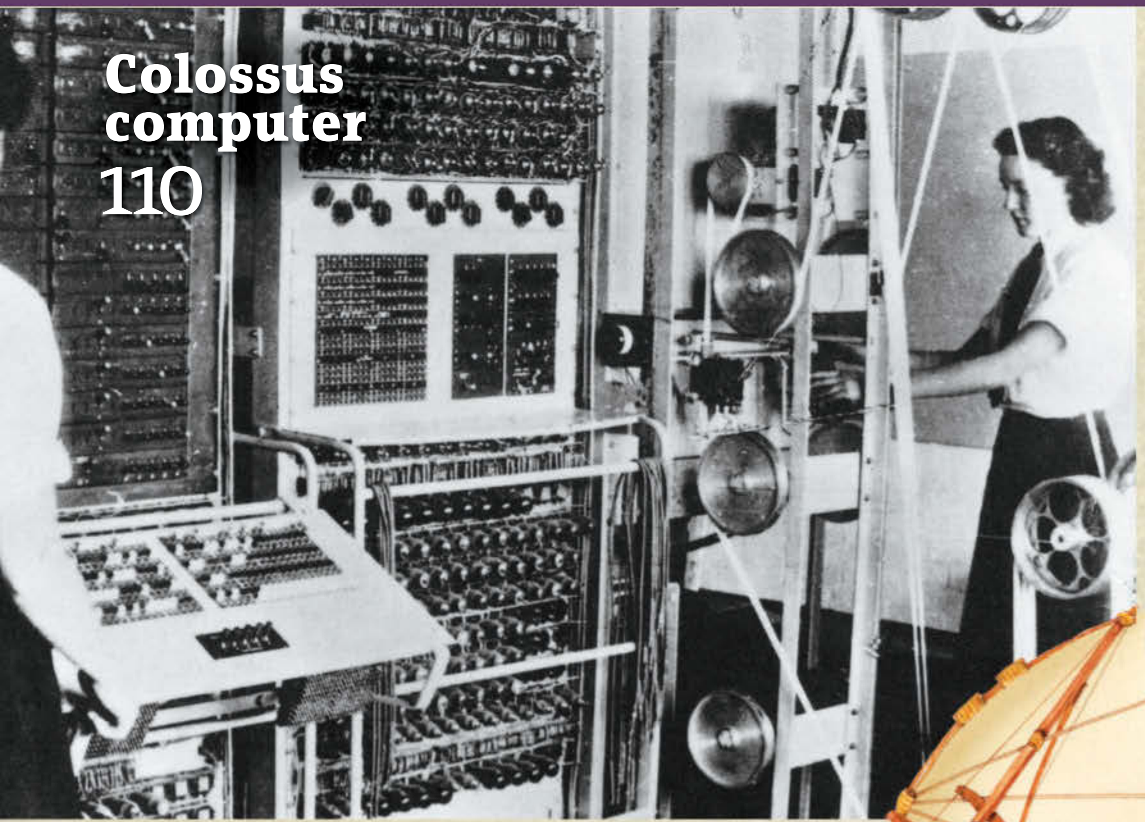

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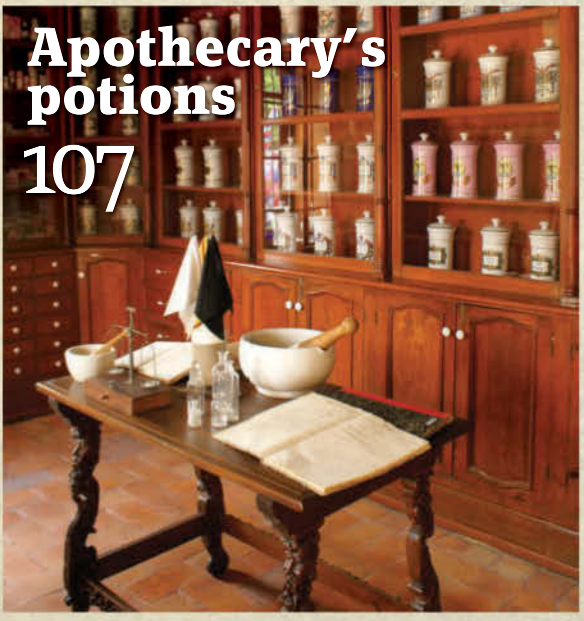

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History's MOST GRUESOME inventions

From brutal torture devices to bizarre medical treatments, these terrifying contraptions reveal a darker side of innovation

From the wheel to the World Wide Web, we have invented some truly ground-breaking things during our time on Earth. Yet throughout history, inventors have also been known to put their skills to use in horrifying ways, creating contraptions that have caused unimaginable suffering.

In the past, if you committed a terrible crime, a punishment much worse than a long prison sentence often awaited you. From boiling people alive to sawing them in half, execution methods were often developed to be as cruel as possible. These gruesome events were usually carried out in public to deter others from committing the same crime.

But even if you weren't sentenced to death, there were plenty of ghastly implements that could be used to torture you instead. Typically used to extract a confession or information about accomplices, torture was popular in medieval times, with the screams of victims echoing from castle dungeons across Europe.

War has also inspired a selection of horrific innovations. While guns and bombs killed instantly, chemical weapons could draw out death for several agonising days – thankfully, this form of warfare is now prohibited.

We are also lucky that some medical devices from history are no longer used. Despite being designed with good intentions, many medieval procedures were truly stomach-churning, making a trip to the doctor quite the ordeal. So be grateful these inventions are before your time...

DID YOU KNOW? *Historical records showed that the brazen bull was still in use during Roman times, used by Emperor Hadrian*

The brazen bull

Turning the screams of the dying into the roar of a beast

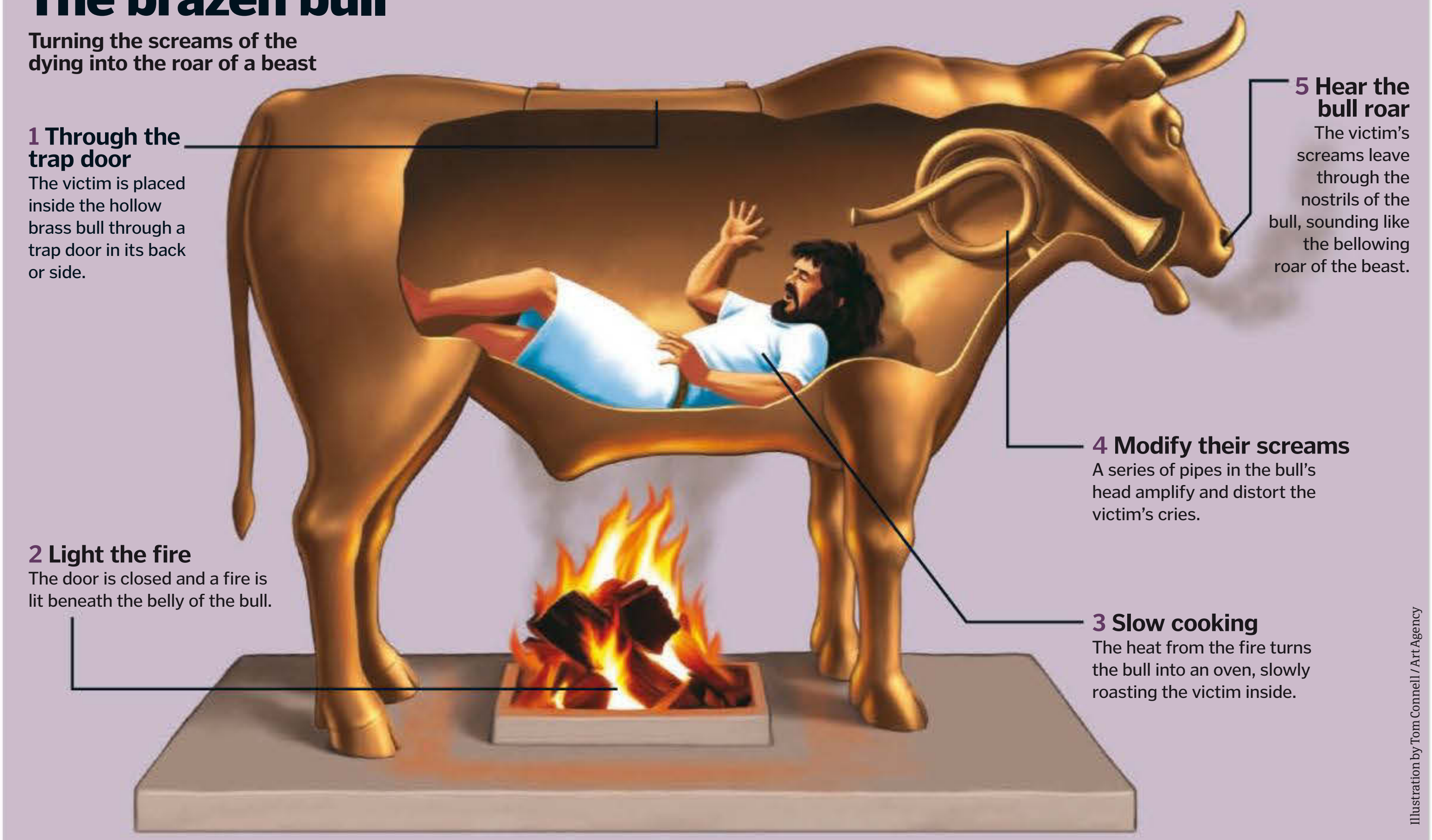

1 Through the trap door
The victim is placed inside the hollow brass bull through a trap door in its back or side.
2 Light the fire
The door is closed and a fire is lit beneath the belly of the bull.
3 Slow cooking
The heat from the fire turns the bull into an oven, slowly roasting the victim inside.
4 Modify their screams
A series of pipes in the bull's head amplify and distort the victim's cries.
5 Hear the bull roar
The victim's screams leave through the nostrils of the bull, sounding like the bellowing roar of the beast.

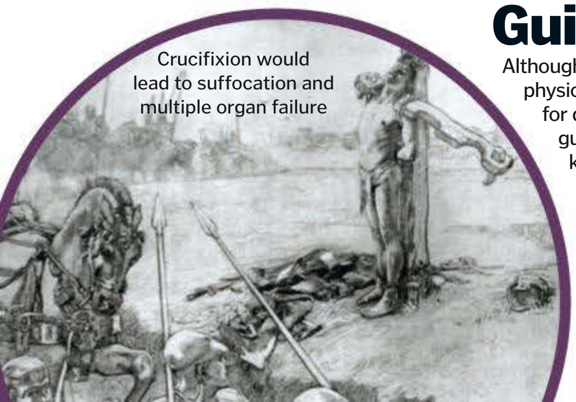
Illustration by Tom Connell / Art Agency

© Corbis; Look & Learn

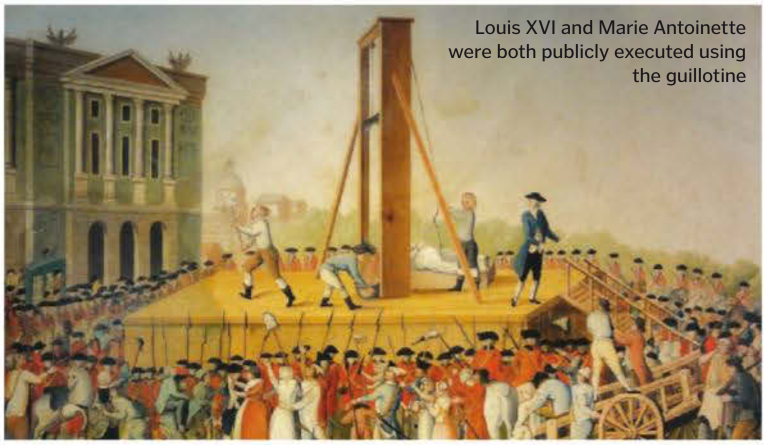
One of the most brutal methods of execution ever created took the form of a hollow bull statue. Invented in Ancient Greece by Perillus, a bronze worker in Athens, it was given as a gift to a cruel tyrant named Phalaris of Agrigentum. As well as roasting criminals alive, the device doubled as a musical instrument, converting the victim's desperate cries into what Perillus described as "the tenderest, most pathetic, most melodious of bellowings". Distrustful of the inventor's claims, Phalaris ordered Perillus to climb inside and prove the device's musical capabilities. As soon as he was inside, Phalaris shut the door and lit a fire beneath. However, rather then letting him die at the hands of his own creation, Phalaris had him removed and thrown off a cliff instead.

Crucifixion

Devised over 2,500 years ago as punishment for the most serious crimes, crucifixion would kill victims in a horribly drawn-out and painful way. With their wrists and feet nailed or tightly bound to a cross, and their legs broken by the executioners to speed up death, the victim's weight would be transferred to their arms. This would gradually pull the shoulders and elbows out of their sockets, leaving the chest to bear the weight. Although inhaling would still be possible, exhaling would be difficult and the victim would eventually suffocate due to a lack of oxygen. This excruciating process could take 24 hours.



Crucifixion would lead to suffocation and multiple organ failure



Louis XVI and Marie Antoinette were both publicly executed using the guillotine

Guillotine

Although beheading methods had already been around for centuries, in 1789 French physician Dr Joseph Guillotin proposed a much more efficient and humane device for decapitation. When the executioner released the rope holding the guillotine's weighted blade in place, it would drop onto the victim's neck, killing them in a fraction of a second. This helped to eliminate the human error that was common with axe and sword beheadings, sometimes requiring multiple swings to fully remove the head. Although quick, guillotine executions were popular spectator events during the French Revolution and the guillotine operators became national celebrities.

Electric chair

Electrocution was adopted as a quicker and supposedly less painful method of execution than hanging in the 1880s. The victim has their head and one calf shaved to reduce resistance to electricity before being strapped in across their waist, arms and legs. A moistened sponge is placed on their head and an electrode in the shape of a metal skullcap is secured on top. Another electrode is attached to their shaved leg before the power is switched on. 2,000 volts pass through their body, paralysing the respiratory system and causing cardiac arrest.

Electrocution is still used as a method of execution in some US states

Inside a torture chamber

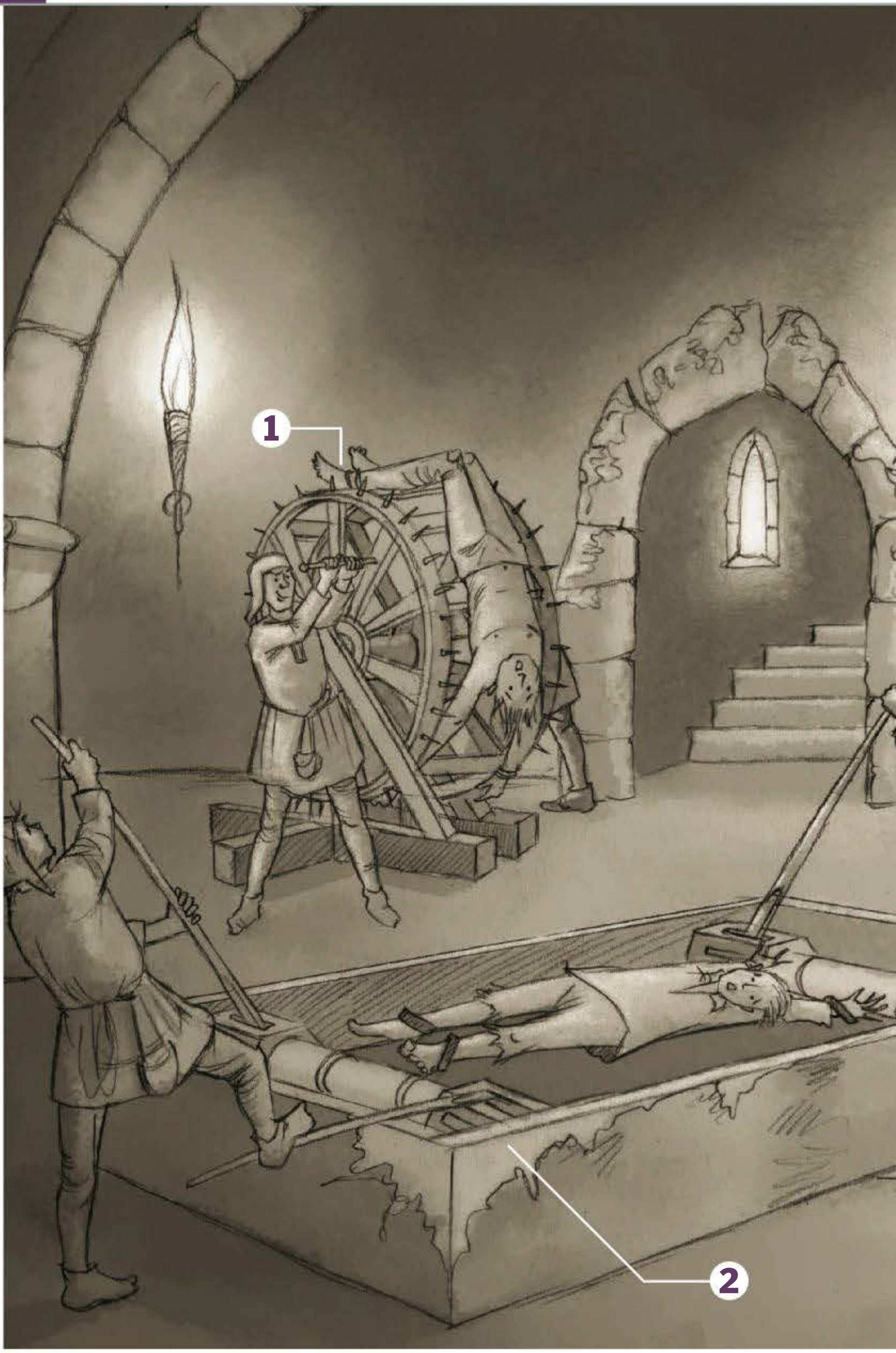
The terrifying devices that inflicted intense pain

Torture has been used as a method of punishment and interrogation for centuries, with the Ancient Greeks and Romans regularly torturing criminals as part of their justice system. However, by the Middle Ages torture had become particularly prevalent, especially in response to crimes of treason. If you had been disloyal to the sovereign and your country, a whole plethora of horrifying torture devices awaited you.

Torture was usually conducted in secret, with most medieval castles featuring an underground dungeon in which these diabolical deeds took place. A great deal of ingenuity and artistic skill went into developing instruments that would inflict the maximum amount of pain. Often simply threatening to use one on a person was enough to get them to confess, while others would quickly give in after seeing it used on a fellow prisoner. Some torture devices were designed to only inflict pain, but others would result in a slow, drawn-out death that prolonged suffering until the victim drew their last breath.

> *"Often simply threatening to use torture on a person was enough to get them to confess"*

However, even if a prisoner was lucky enough to survive the torture, they were usually left severely disfigured and often had to be to be carried to their resulting trial as they could no longer walk on their own. From the mid-17th century onwards, torture became much less common as there was much speculation about its effectiveness. Many prisoners would say anything to end their suffering, so it often produced inaccurate information or false confessions. It wasn't until 1948 that the United Nations General Assembly adopted the Universal Declaration of Human Rights, banning the use of torture.



① Breaking wheel

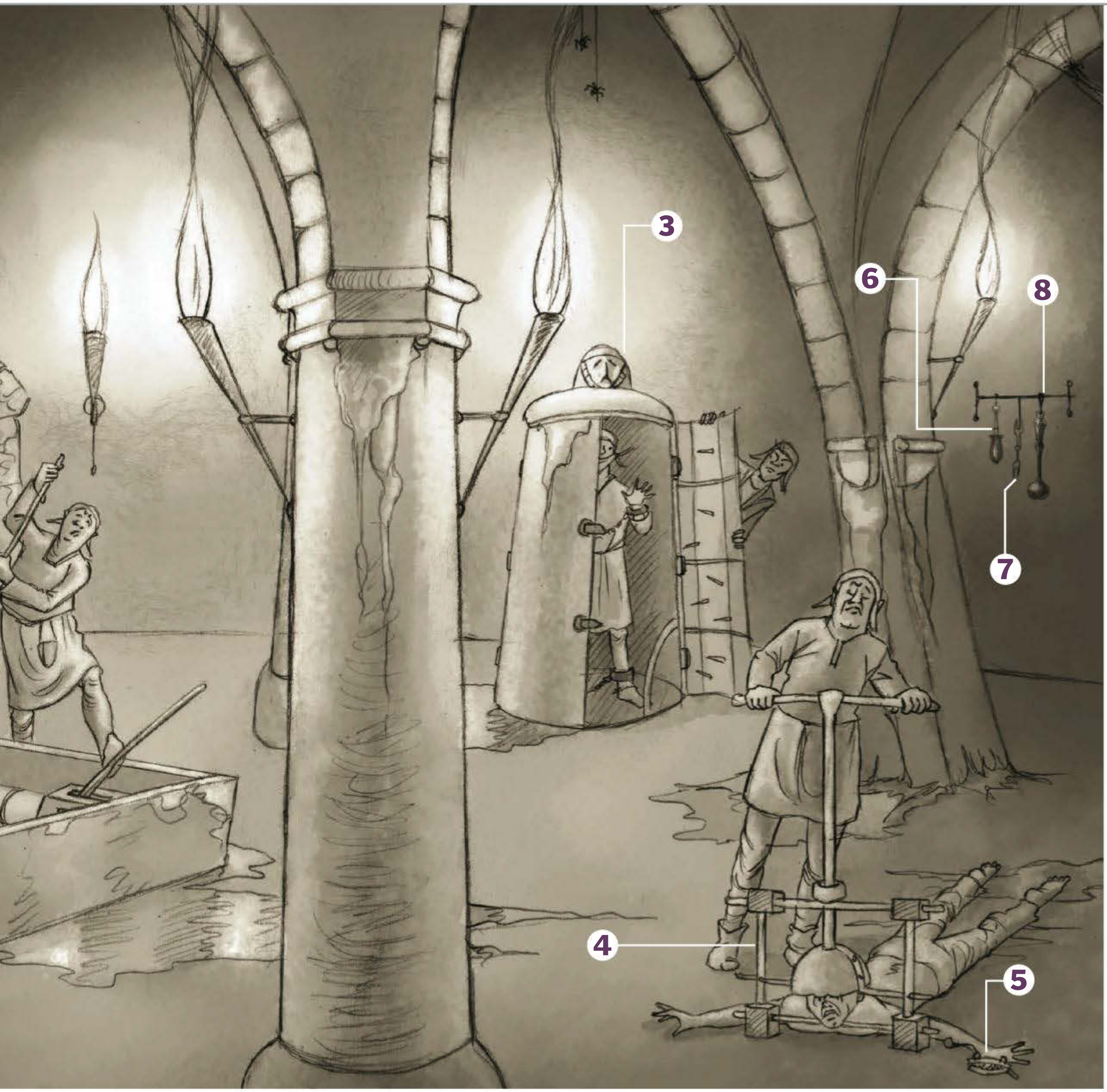
With the victim's limbs tied to the spokes of this large wooden wheel, it would be slowly revolved. As it spun, the executioner would bludgeon the victim's arms and legs with an iron hammer, shattering their bones one by one. If the victim survived this, they were placed on top of a large pole so birds could peck at their body until they eventually died of dehydration, which could take several days.

② The rack

With their hands and feet tied to rollers at each end of the wooden frame, the torture victim would be subjected to intense interrogation. If they failed to confess to their crimes or give up the information the torturer was looking for, a crank would be turned to rotate the rollers. This would pull on the ropes, gradually stretching the victim's body and causing intense pain, eventually dislocating their limbs.

③ Iron maiden

A series of menacing spikes protruded from the interior of this iron chamber. With the victim inside, the door was closed slowly, causing the strategically placed spikes to pierce the body. However, the spikes were not long enough to be instantly fatal. Instead, the victim would be left to slowly bleed to death.



④ Head crusher

With the victim's chin placed over the bottom bar and their head beneath the metal cap, the executioner would slowly turn the screw to bring the two together, only stopping if the victim gave the right answers. As the victim's head was crushed, their teeth would shatter into their jaw and their eyes would pop out from their sockets.

⑤ Thumbscrews

Used as punishment or a method of extracting information, the victim's fingers, thumbs or toes were placed between two horizontal metal bars. When the screw was turned, the two bars were pressed together, crushing the digits inside. Some thumbscrews even featured metal spikes on the bars to increase the pain.

⑥ Choke pear

Also known as the 'pear of anguish', this device was inserted into one of the victim's orifices, such as their mouth. When the key or crank was turned, the 'petals' of the pear-shaped end would slowly open up, painfully mutilating the victim's insides, but not causing death.

⑦ Heretic's fork

Usually reserved for blasphemers, this metal rod with two prongs at either end was attached to a leather strap around the victim's neck. One end would pierce their chin, while the other dug into their sternum, causing immense pain if they attempted to move their jaw or neck, making it more or less impossible to talk.

⑧ Lead sprinkler

Deceptively designed to look like a holy water sprinkler, this device was actually filled with molten lead, acid or boiling hot oil or water. The long handle was shaken to shower the victim's body with the substance inside. This caused horrific burns and was potentially lethal.

Miserable medicine

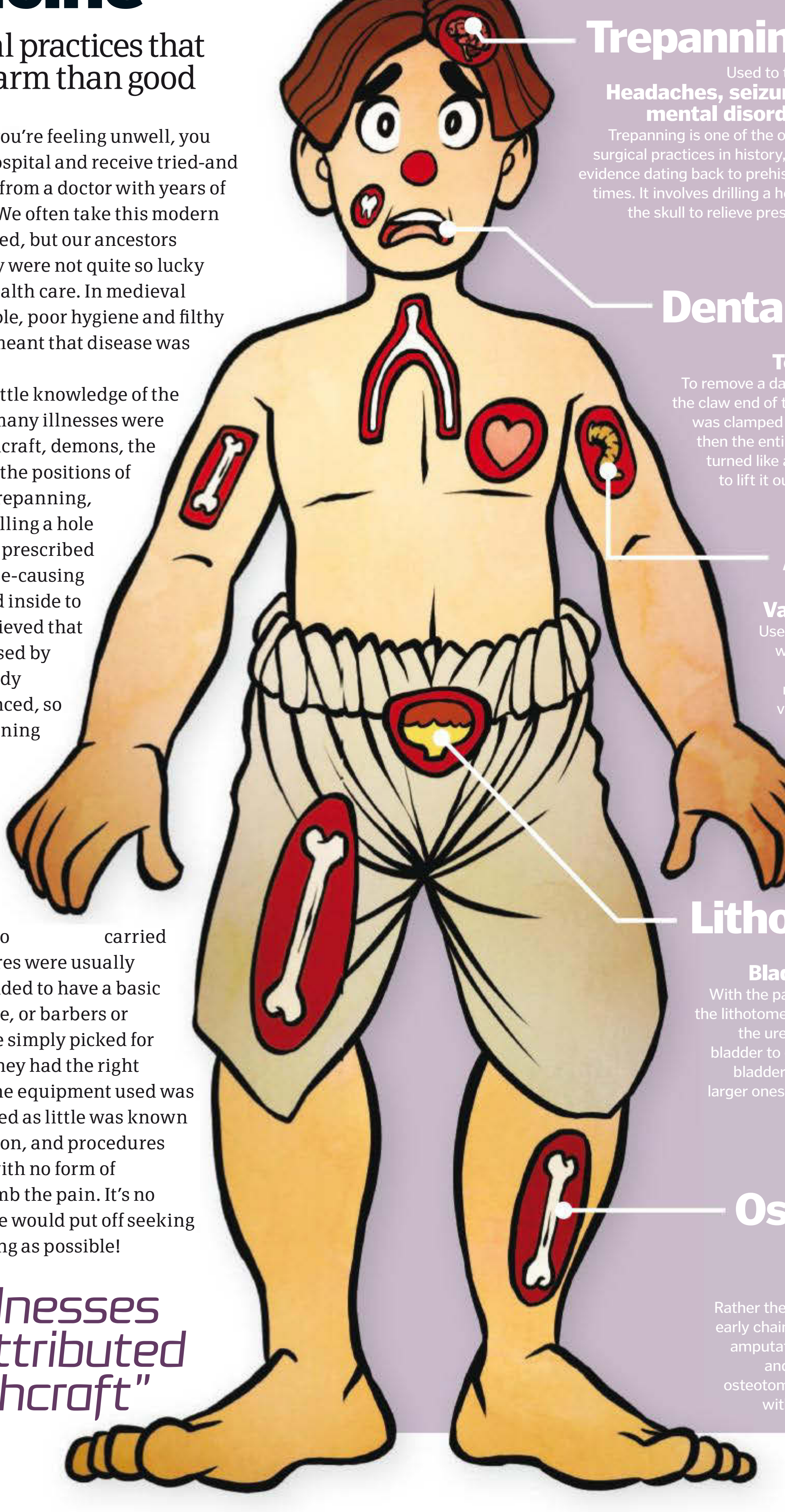
The medical practices that did more harm than good

Nowadays, when you're feeling unwell, you can visit a clean hospital and receive tried-and tested-treatments from a doctor with years of medical training. We often take this modern medicine for granted, but our ancestors throughout history were not quite so lucky when it came to health care. In medieval England for example, poor hygiene and filthy living conditions meant that disease was very common.

However, with little knowledge of the human anatomy, many illnesses were attributed to witchcraft, demons, the will of god or even the positions of celestial bodies. Trepanning, which involves drilling a hole into the skull, was prescribed to allow the disease-causing evil spirits trapped inside to escape. Others believed that diseases were caused by the fluids in the body becoming unbalanced, so bloodletting – draining the blood from a particular part of the body – was thought to restore that balance to normal levels.

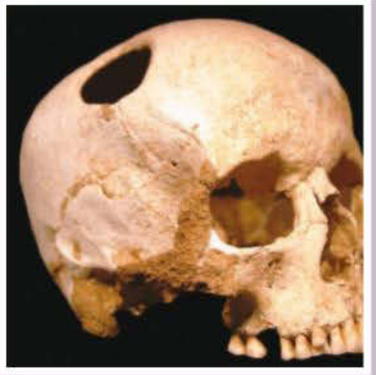
The 'doctors' who carried out these procedures were usually monks, as they tended to have a basic medical knowledge, or barbers or butchers who were simply picked for the task because they had the right tools for the job. The equipment used was very rarely sterilised as little was known about contamination, and procedures were carried out with no form of anaesthesia to numb the pain. It's no wonder that people would put off seeking treatment for as long as possible!

> *"Many illnesses were attributed to witchcraft"*



Terrifying treatments

Horrifying medical instruments and procedures from the past

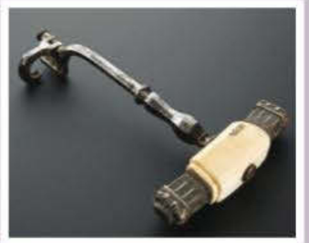


Trepanning

Used to treat:

Headaches, seizures, mental disorders

Trepanning is one of the oldest surgical practices in history, with evidence dating back to prehistoric times. It involves drilling a hole in the skull to relieve pressure.



Dental key

Used to treat:

Toothache

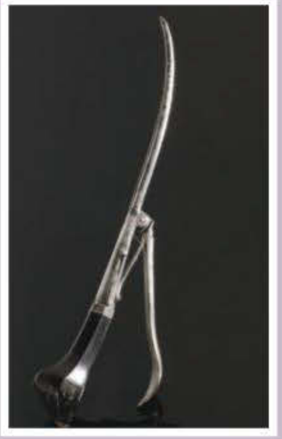
To remove a damaged tooth, the claw end of the dental key was clamped around it and then the entire device was turned like a key in a lock to lift it out of the gum.

Artificial leech

Used to treat:

Various infections and diseases

Used for bloodletting, a popular treatment for a wide range of medical conditions, this device mimicked the action of reel leeches, with rotating blades that cut into the skin while a vacuum in the cylinder sucked out the blood.

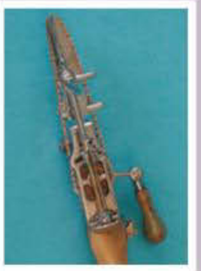


Lithotome

Used to treat:

Bladder stones

With the patient still awake, the lithotome was inserted up the urethra and into the bladder to grip onto smaller bladder stones or cut up larger ones so they could be passed naturally.



Osteotome

Used to treat:

Infections in the arms or legs

Rather then cutting down trees, this early chainsaw was actually used to amputate limbs. Unlike a hammer and chisel, the hand-cranked osteotome could cut through bone without causing it to splinter.

DID YOU KNOW? *World War I soldiers described the smell of chlorine gas as a combination of pepper and pineapple*

Weapons of war

The chemical arms race changed warfare forever

Chemical weapons

On 22 April 1915, Germany shocked the world by launching the first large-scale gas attack in war. After waiting several weeks for the wind to blow in the right direction, German soldiers released clouds of chlorine gas near the enemy trenches in Ypres, suffocating the unprepared Allied troops. Although The Hague Convention of 1899 prohibited the use of poisonous weapons, Germany justified its actions by claiming that France had already broken the ban by deploying tear gas grenades in 1914. The chlorine gas attack kick-started a chemical arms race, and by the end of World War I around 50 different chemicals had been used on the battlefield. The most prevalent were chlorine, phosgene and mustard gas, which would result in slow and painful deaths if soldiers were exposed to large enough quantities. Eventually, gas masks were developed for protection, but chemicals such as mustard gas could still cause horrific blisters if they came into contact with the skin. Among the most devastating chemical weapons are nerve agents, such as sarin, which attack the nervous system. Even small concentrations can be lethal, killing in mere minutes.

Cl_2

Chlorine

Appearing as a pale green cloud with a strong bleach-like odour, chlorine gas reacts with water in the lungs to form hydrochloric acid. This damages the lung tissue, causing coughing, vomiting and eventually death.

$COCl_2$

Phosgene

This colourless gas with a musty odour reacts with proteins in the alveoli, tiny air sacs found in the lungs. This leads to fluid in the lungs and eventually suffocation, but the symptoms can take up to 48 hours to manifest.

$C_4H_8Cl_2S$

Mustard gas

With the odour of garlic, horseradish or sulphur, yellow-brown clouds of mustard gas cause chemical burns on the skin, eyes and respiratory tract, leading to large blisters, temporary blindness and shortness of breath.

$C_4H_{10}FO_2P$

Sarin

Colourless, tasteless and odourless, this gas blocks normal communication between nerves. The nerve signals become stuck 'on', and muscles are unable to relax. This can lead to spasms, paralysis and asphyxiation.

The Geneva Protocol

By the end of World War I, over 125,000 tons of poison gas had been deployed in battle. Although it was only responsible for less than one per cent of the war's total fatalities, the psychological terror it had inflicted on soldiers was immense. On 17 June 1925, seven years after the war had ended, the Geneva Protocol was introduced, prohibiting the use of chemical and biological weapons. 138 states have now signed the treaty.

38 states originally signed the Geneva Protocol to ban the use of chemical weapons

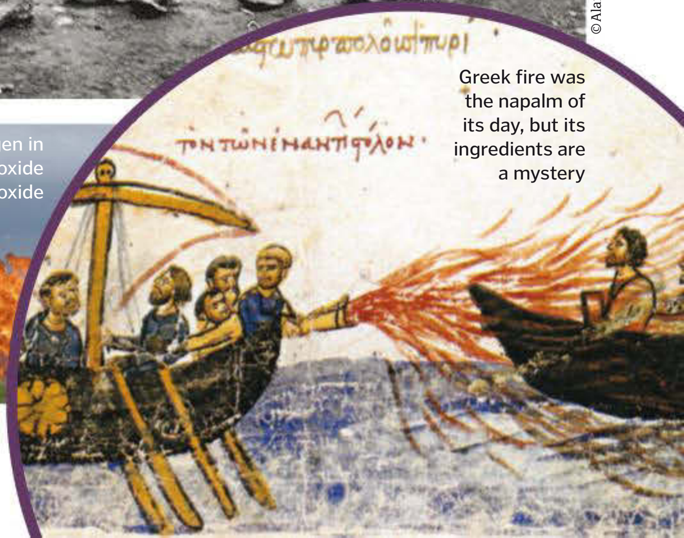
Napalm

Napalm is a flammable liquid with a gel-like consistency, allowing it to stick to surfaces easily. In a bomb, it is combined with gasoline or jet fuel to explode upon impact, burning at over 2,760 degrees Celsius. Contact with skin can result in severe burns and even death by asphyxiation. When ignited, napalm generates carbon monoxide and removes oxygen from the air, suffocating those in the vicinity. Some of the greatest atrocities of war were caused by napalm.

Napalm fires combust oxygen in the air, turning carbon dioxide into carbon monoxide

Greek fire

Developed by the Byzantine Greeks in the 7th century, Greek fire was a flammable liquid that could burn on water, making it particularly effective for naval warfare. It was sprayed at the enemy using early flamethrower devices, or thrown in primitive hand grenades. The resulting fire could only be extinguished with sand, vinegar or urine. The true ingredients are a mystery, but scientists believe it could have contained petroleum, sulphur and pine tar.

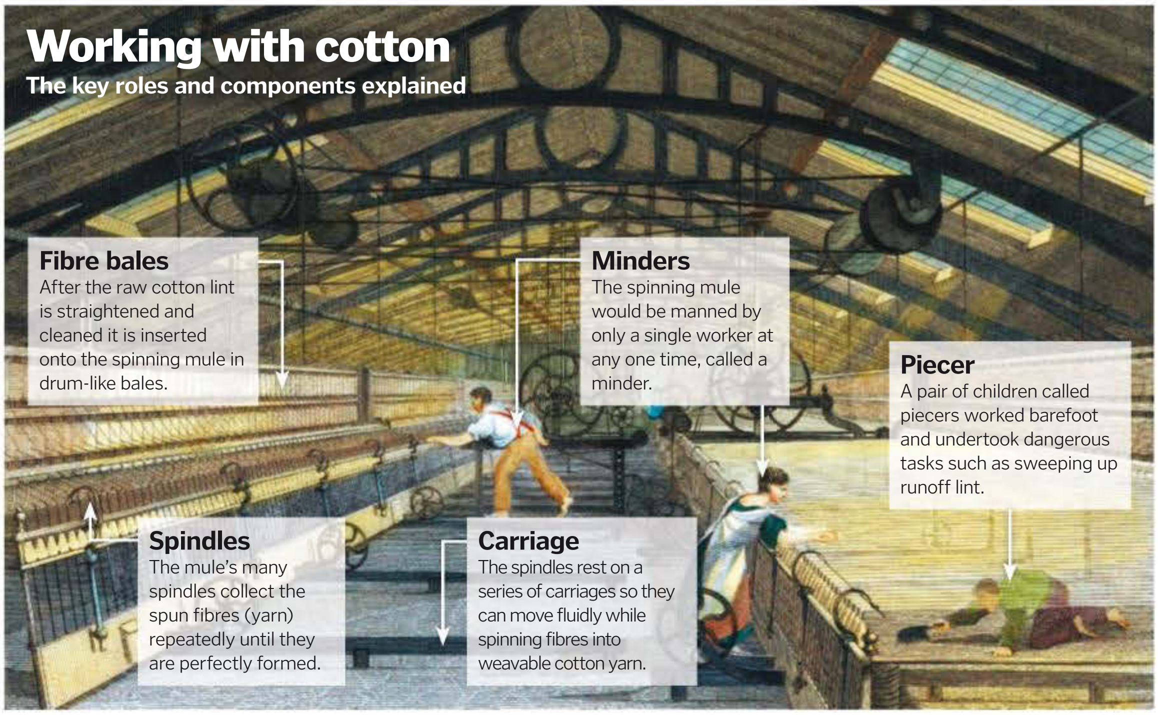


Greek fire was the napalm of its day, but its ingredients are a mystery

© Alamy;SPL; WIKI; Dreamstime

Working with cotton

The key roles and components explained



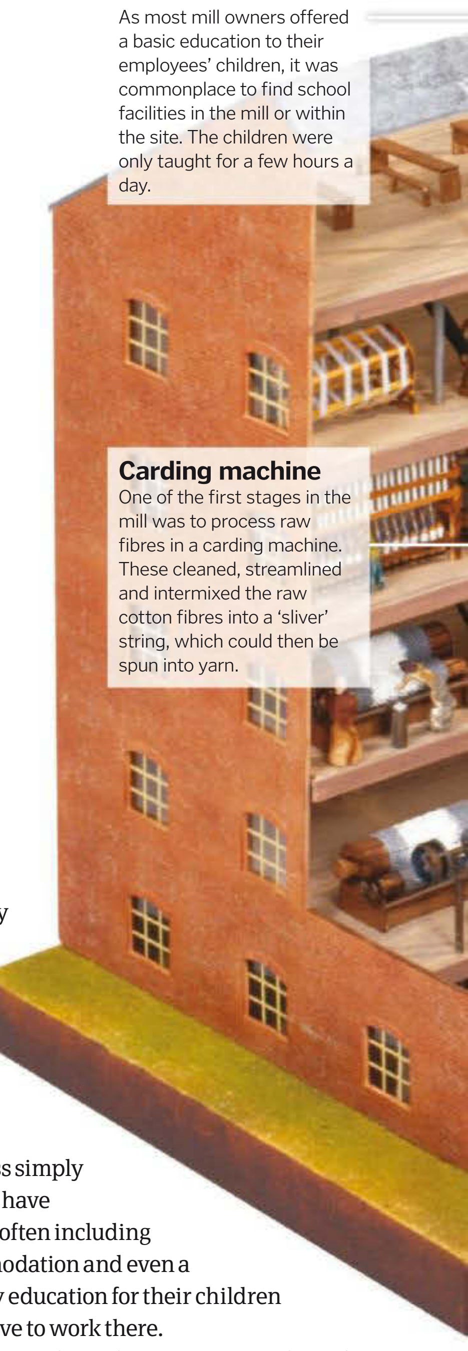
Fibre bales
After the raw cotton lint is straightened and cleaned it is inserted onto the spinning mule in drum-like bales.

Minders
The spinning mule would be manned by only a single worker at any one time, called a minder.

Piecer
A pair of children called piecers worked barefoot and undertook dangerous tasks such as sweeping up runoff lint.

Spindles
The mule's many spindles collect the spun fibres (yarn) repeatedly until they are perfectly formed.

Carriage
The spindles rest on a series of carriages so they can move fluidly while spinning fibres into weavable cotton yarn.



Mill school
As most mill owners offered a basic education to their employees' children, it was commonplace to find school facilities in the mill or within the site. The children were only taught for a few hours a day.

Carding machine
One of the first stages in the mill was to process raw fibres in a carding machine. These cleaned, streamlined and intermixed the raw cotton fibres into a 'sliver' string, which could then be spun into yarn.

Inside a cotton mill

Understand the workings of one of the cornerstones of the Industrial Revolution and how cotton changed the world

In the 19th century, cotton production was one of the most profitable enterprises around. Western society had long been split into a two-tier system, with the aristocracy controlling over 90 per cent of the nation's wealth, with the rest left virtually penniless. The Industrial Revolution quickly changed that, with a new merchant middle-class becoming a significant financial power.

With the middle class's ascension came an increased need for quality fabric products. But while the need for cotton had grown, the cotton industry itself was still largely restricted to a series of cottage industries – small home-grown businesses staffed by manual labourers who were unable to keep pace with demand.

Luckily, automated machines such as the self-actuating spinning mule and power loom were invented that enabled cotton to be processed, spun and woven at a scale that not only could meet demand but also rendered these cottage industries obsolete.

And so was born the cotton mill. These were staffed with the remnants of the former cottage industries as well as hundreds and thousands of others, with workers no longer required to hold proficiency in traditional skills such as sewing but instead simply be capable of operating the machines that now did everything for them.

Conditions were poor for the workers, with people of all ages – including children – exposed to potentially crippling machines as well as hot and dusty conditions that often led to fatal ailments. Workers frequently lost fingers and even limbs while operating the machinery too.

Despite the dire conditions, the sheer number of jobs available – to women and men alike, granting the former an independent income – saw the working class flock to cotton mills, with people often travelling across the country to cotton hotspots like Lancashire to earn some money. Many mill owners also offered packages that, before that point, the working class simply would never have dreamed of, often including free accommodation and even a rudimentary education for their children as an incentive to work there.

As the Industrial Revolution came to a close, the industry went into decline. By the early-20th century, cotton yarn and fabrics were now being produced all over the world, with new industrial heartlands emerging in Asia. This meant that by 1950 the age of the cotton mill was over, with its once bustling rooms falling silent.

A stitch in time…

Follow the key developments in the history of cotton with this quick timeline

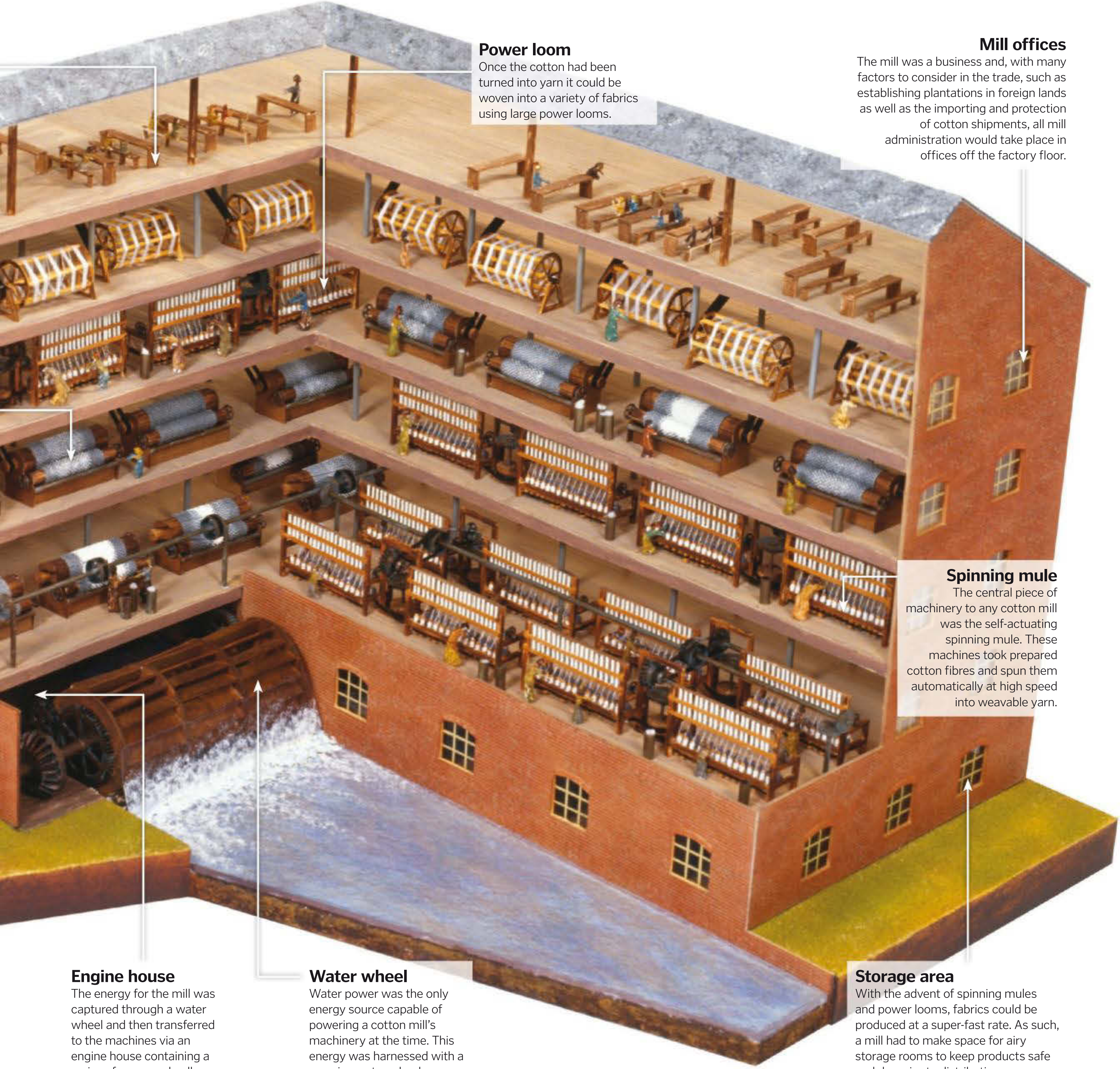
5000 BCE
Treated cotton bolls and pieces of simple cotton cloth in Mexican caves date to around 7,000 years ago.

3000 BCE
The Harappan civilisation in what is Pakistan today grows, spins and weaves cotton during the Bronze Age.

800 CE
Arab merchants begin importing Eastern-made cotton into Europe in large quantities for the first time.

1500
Cotton is now used throughout the world. Its production remains restricted to cottage industries though.

DID YOU KNOW? *In 1833, England's largest cotton mill employed over 1,500 people*



Power loom
Once the cotton had been turned into yarn it could be woven into a variety of fabrics using large power looms.

Mill offices
The mill was a business and, with many factors to consider in the trade, such as establishing plantations in foreign lands as well as the importing and protection of cotton shipments, all mill administration would take place in offices off the factory floor.

Spinning mule
The central piece of machinery to any cotton mill was the self-actuating spinning mule. These machines took prepared cotton fibres and spun them automatically at high speed into weavable yarn.

Engine house
The energy for the mill was captured through a water wheel and then transferred to the machines via an engine house containing a series of gears and pulleys.

Water wheel
Water power was the only energy source capable of powering a cotton mill's machinery at the time. This energy was harnessed with a massive water wheel.

Storage area
With the advent of spinning mules and power looms, fabrics could be produced at a super-fast rate. As such, a mill had to make space for airy storage rooms to keep products safe and dry prior to distribution.

1730
The first machines to automatically process and spin cotton are put into use, speeding up production.

1741
The world's first mill specifically designed to spin cotton mechanically is opened by English engineers Lewis Paul and John Wyatt.

1794
US inventor Eli Whitney patents the 'cotton gin', a machine that can separate cotton fibres from their seeds.

1824
English inventor Richard Roberts creates his most famous machine, the spinning mule, which can spin cotton at a rate unimaginable to manual spinners.

1855
In the mid-19th century cotton production enters a new golden age, with huge mills being built.

1950
100 years on many mills have closed and those that survive become increasingly automatic, with electric engines.

© DK Images; Getty; Grjatoi

Medieval writing equipment

Why we used quills for over 1,300 years

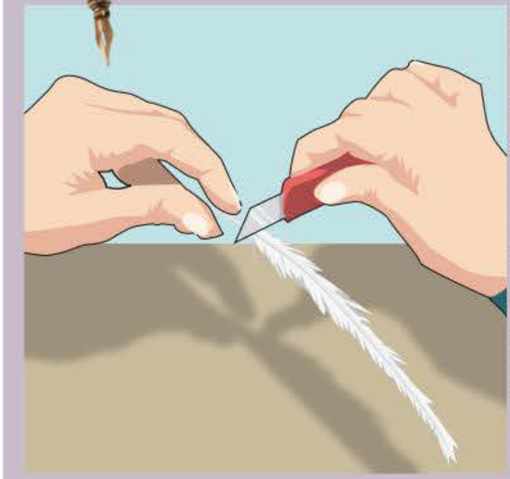
Before the invention of the pen, most people used quills to write with. These were stripped bird feathers, usually from geese. Swan feathers were very sought after but geese, crow, owl and turkey feathers were simpler to obtain.

Quills were easy to supply, comfortable to hold and tapered down to a point so the writer could create all the subtle curves and lines of fine handwriting.

The first record of their use was around the 6th century by European monks, replacing the reeds they had been using up until then. Feathers were stripped, buried in hot sand to harden, hollowed out and then filled with ink. They were time-consuming to make and had to be refilled and reshaped regularly, but continued to be the main writing implement until the metal pen became popular in the mid-19th century.

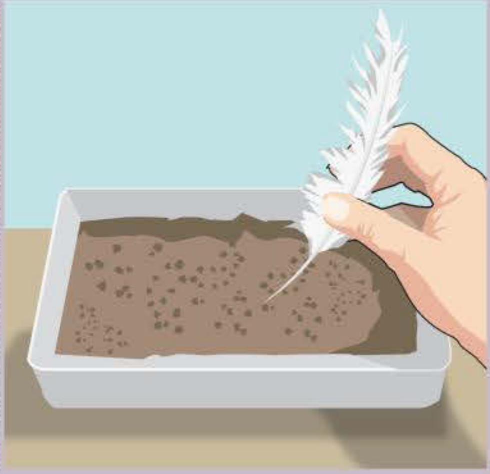
How to make a quill

Travel back through time to the Middle Ages and write with feathers



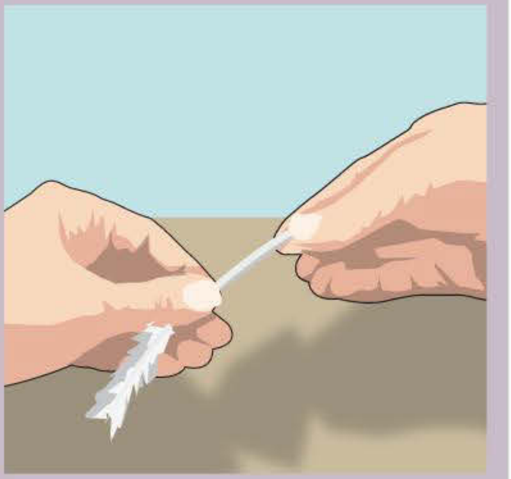
Prime your feather

Scout around near a river or lake for a feather that has been dropped by a swan or goose. Ideally it should be around 15cm (6in) long and intact. Using a Stanley knife, very carefully shave off the fluffy feathers at the pointy end. You should be able to grip the quill without touching any feathers. Then place the feather in a bowl of water and leave it overnight to soak.



Toughen and shape

Heat sand in the oven at 175°C (350°F) and bury the feather, using oven gloves to avoid burns. Wait until the sand has cooled and remove the hardened feather. From about 2.5cm (1in) above the tip, slice down at an angle of around 45 degrees to the tip of the feather. Make a small, flat cut on the opposite side of the tip. There should now be two spikes on the tip that you need to pinch together.



Finishing off

Shave the pinched end so it is nice and smooth and you should have a feather tapering nicely to a point. Dip your quill in the ink where it should soak up the writing fluid. There should be enough to write a fair few lines, depending on how tightly you've pinched it together. The tighter you've pinched it, the more ink it should retain. Take it out and begin writing like a medieval scribe!

The first hearing aids

From 19th-century ear trumpets to microchips

Although they may look like something out of a cartoon, ear trumpets were used frequently throughout the early-19th century. The first type of hearing aid had a large surface area that amplified sound that was directed toward the ear. They were made of metal, silver, wood or animal horns and were incredibly bulky. However, as their use became more widespread, they featured a collapsible design so the ear trumpet could be carried in pockets and removed when necessary. Horns were so popular that even midwives would use a similar instrument to the ear trumpet for listening to pregnant ladies' wombs.

Early hearing aids could hardly be described as 'inconspicuous'

© Thinkstock; Ed Crooks; Getty

DID YOU KNOW? *The term 'apothecary' originates from the Latin 'apotheca', which is where spices and herbs were stored*

Apothecary secrets

What are the origins of the pharmaceutical industry?

It's thought the first apothecary – which can mean both pharmacy or pharmacist – emerged in Ancient Babylon and was introduced to the West by Galen, a Roman doctor. It originally revolved around the preservation of food, but its focus shifted to the relationship of drugs and medicines with living systems and the process of recording symptoms for the cure and prevention of disease.

The preparation and selling of medicines was handled by an apothecary after the Society of Apothecaries was established in London in 1617. By the 19th century, their role had evolved. The Apothecaries Act in 1815 meant that chemists now had to have formal qualifications and provide medical care and surgery to patients, while new chemist shops would look after the retail side. The practice evolved into pharmacology as new substances were developed such as morphine, strychnine, atropine and quinine. Morphine, for example, was isolated in 1805 by Friedrich Setürner who stirred and heated opium in methanol.

Apothecaries remained prominent throughout the 20th century, with about 100 apothecaries still in the USA during the 1960s. The age of apothecaries all but came to an end in the 1980s as large chain drug stores superseded them.

A replica of an 18th-century apothecary shop in Mexico

Apothecary treatments

1 Artificial leech

Rather than using real leeches for bloodletting, a man-made alternative was created by Carl Baunscheidt in the mid-19th century. It was a pen-like device with a group of tiny needles on the end.

2 Vesiculation

Used to combat madness and hypochondria, this involved intentionally raising blisters on the skin.

3 Clysters

A medicine injected to help nutrition and cleanse the bowels. Along with vomiting and bloodletting this was seen as a way of 'purging' the body of bad elements.

4 Chamomile

A flower that had sedating and anti-inflammatory effects, it was prescribed for colds and infections and was one of many plants used in medicine.

© Science Museum/SSPL, Alamy

Compass of the oceans

The device mariners once used to navigate the seven seas

The age of discovery owes a lot to the mariner compass. The journeys of pioneering explorers such as Columbus and Vasco de Gama would never have been undertaken if it wasn't for the instrument's ability to help navigate Earth's vast oceans. Like so many instruments of its time, it was originally invented in China. The mariner's compass, or dry compass, was first introduced to Europe around 1300.

Its key components were the gimbal, which allowed the compass to rotate, a compass card that marked the directions on its face and a lubber line for reference, all of which were held in a brass frame and wooden box for protection.

Later, in 1745, Dr Gowin Knight designed a needle of magnetised steel that lasted longer and worked with much more precision than the previous version had ever done. This development was essential to lengthy ocean expeditions, as the needles would not need to be replaced or remagnetised. An upgrade of this system was devised by silversmith Francis Crow in 1813; the new 'liquid compass' had the needle floating on a mix of alcohol and water, again improving on the mechanism's accuracy.

Without a compass, Columbus would've never reached America

How vinyl records were made

Take a spin around this retro method of mass-producing music

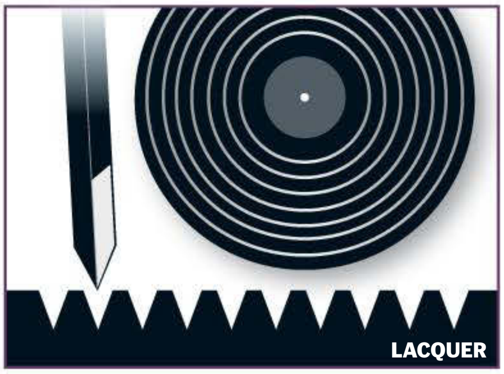
As the vinyl disc spins on the record player, a needle – or stylus – moves along the grooves on its surface. It vibrates as it traces over the thousands of tiny bumps and the music plays. The tech seems simple compared to an iPod, yet the process to make one of these vinyl records is quite intricate.

Once engineers had perfected the recording in the studio, they would create a master disc. This was made of aluminium and coated with a black lacquer. A machine equipped with an electronic cutting stylus, or needle, would etch the grooves into the lacquer, its path directed by electrical signals from the audio. The finished record was coated with a layer of metal, such as silver or nickel, and this so-called master would form the mould for all the records produced. Liquid nickel was poured into the cast to create a 'stamping record' – a negative version of the record with ridges instead of grooves – and this was connected to a hydraulic press and used to directly print into the vinyl. The stamping record would be lowered onto the vinyl (which was softened by heating with steam) to squeeze it into its final shape and imprint the audio. The disc was then removed, hardened in a water bath, and cut to size using a sharp blade.

Before the records could be sold, a handful were inspected for sound quality. Flawed copies were melted and pressed again.

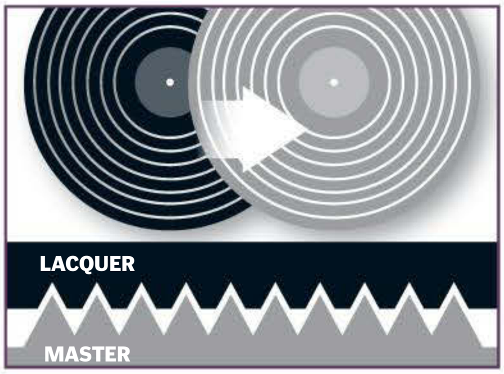
Making a hit record

From the studio to your turntable



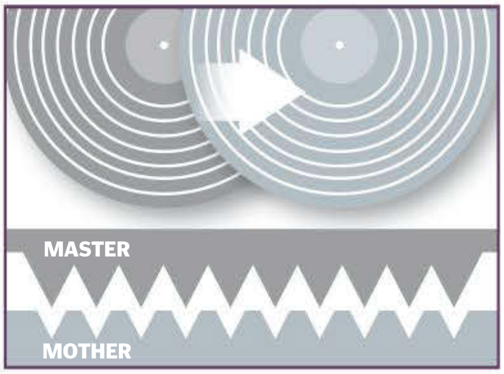
1 Cutting the lacquer

Tiny grooves were etched into the lacquered discs by a record-cutting machine's needle. This was guided by the audio of the specific song.



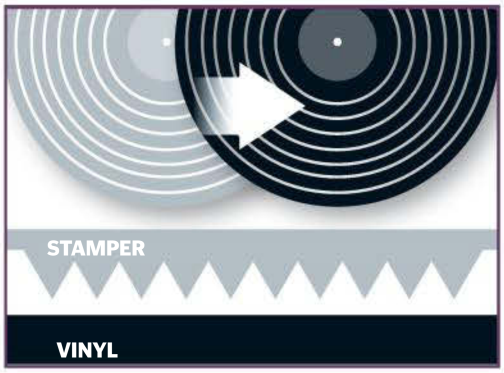
2 Producing the master disc

The lacquer was not tough enough for the production process, so was coated with silver or nickel. It was then peeled off and discarded, leaving the metal master.



3 Creating the 'mother'

The master was re-cut once more to make a mother record. This was then replated to create the 'stamper', which could then be used to mass produce the record.

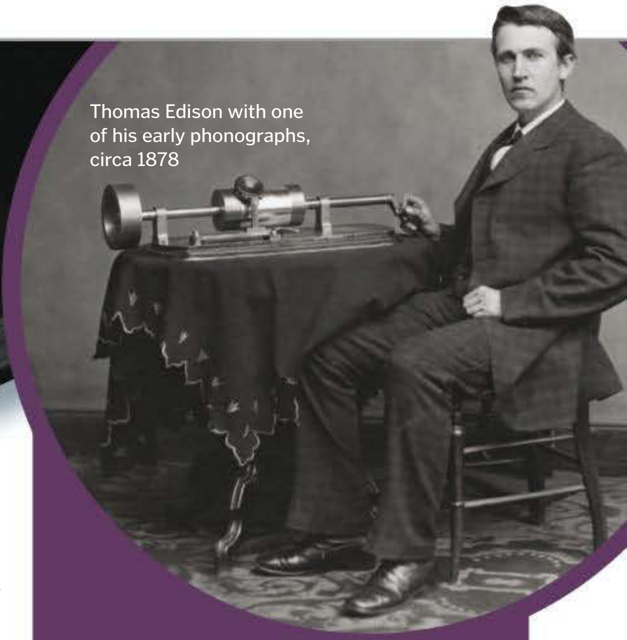


4 Stamping the vinyl

A fresh piece of vinyl was sandwiched between the stamper and a hydraulic press. Steam was used to soften the vinyl, enabling the stamper to imprint it with grooves.

5 Quality control

Before the finished vinyl could be sent to shops, a few were played to check that they were working correctly and that there were no imperfections.



Thomas Edison with one of his early phonographs, circa 1878

Thomas Edison's phonograph

The inventor of the electric light bulb and the motion picture camera was also the grandfather of modern record players. In 1877 Thomas Edison and his assistants were working on a way to record telegraph messages using paper strips wrapped around rollers. He attached a needle to the diaphragm in a telephone mouthpiece, which vibrated with sound energy when someone spoke, creating squiggles on the paper. Once the sound was recorded in this way, it could be replayed by rotating the cylinder in the opposite direction, which dragged a second needle backwards through the indentations the first had made. Edison and his team produced a working prototype, recording their own rendition of *Mary Had A Little Lamb*.

Within six months, Edison had replaced the paper strips with tinfoil to improve the sound quality, and the first phonograph was born. Edison's work paved the way for other inventors to refine and improve the recording process, which eventually led to the record player and vinyl records.

© WIKI

DID YOU KNOW? *Numerous witnesses have reported heads moving, speaking and blinking for a few seconds after decapitation*

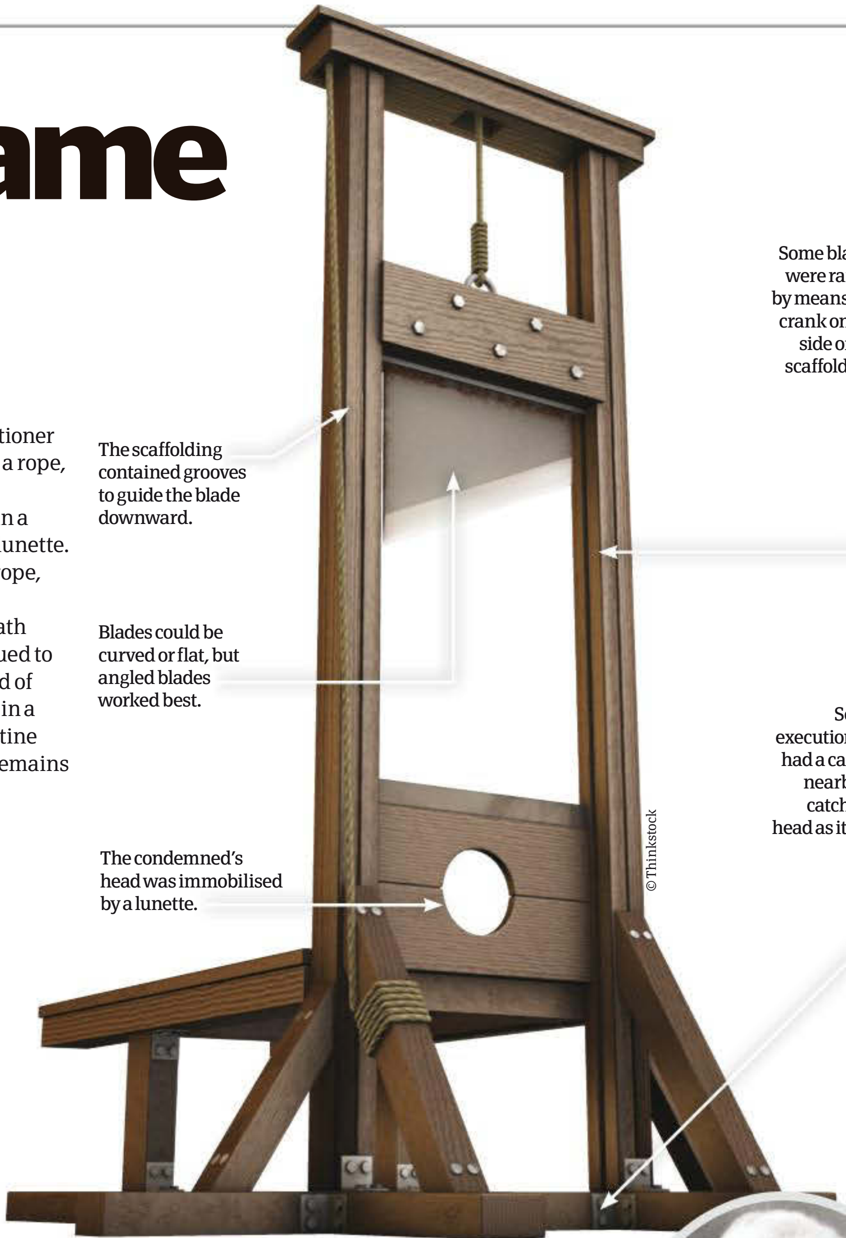
Meet Madame Guillotine

The guillotine was the official method of execution in France until 1981

During the French Revolution, anatomy professor Joseph-Ignace Guillotin proposed that capital punishment in France should be carried out by decapitation on people of all classes because it was the most humane method. Dr Antoine Louis of the Academy of Surgery designed the machine that came to be known as the guillotine after pointing out that beheading by sword was highly impractical.

The guillotine consists of a wooden frame with an angled blade that runs along grooves. After the executioner raises the weighed blade with a rope, the condemned is placed on a platform with his or her head in a round wooden frame called a lunette. The executioner lets go of the rope, allowing the blade to drop.

Until abolishment of the death penalty in 1981, France continued to use the guillotine as its method of execution. Although still legal in a few other countries, the guillotine has not been used since, and remains a relic of the past.



The scaffolding contained grooves to guide the blade downward.

Blades could be curved or flat, but angled blades worked best.

The condemned's head was immobilised by a lunette.

Some blades were raised by means of a crank on the side of the scaffolding.

Some executioners had a casket nearby to catch the head as it fell.

© Thinkstock

Guillotines were made to quicker and more humane

The first telephone

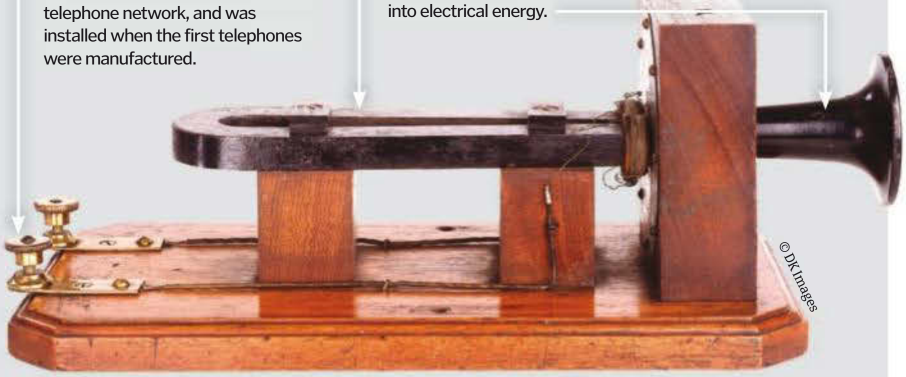
The telephone was a worldwide revolution and the start of instant long-distance communication

The first telephones to be manufactured featured three main parts: a speaker, a microphone and a hook switch, but the first telephone was much more basic.

Alexander Graham Bell, who is credited with the first patent for the telephone, created an instrument that featured a transmitter formed of a double electromagnet in front of which sat a membrane stretched around a ring holding a piece of iron in its middle. The mouthpiece was positioned before the diaphragm and when sounds were directed upon it, it vibrated and the iron moved.

This movement induced currents in the coils of the magnet which were passed along the electric current of the line to the receiver which consisted of a tubular electromagnet. One end of this was partially closed by a thin circular disk of soft iron and as the current was received the disk vibrated and acoustic sounds were emitted.

Alexander Graham Bell, the father of the telephone

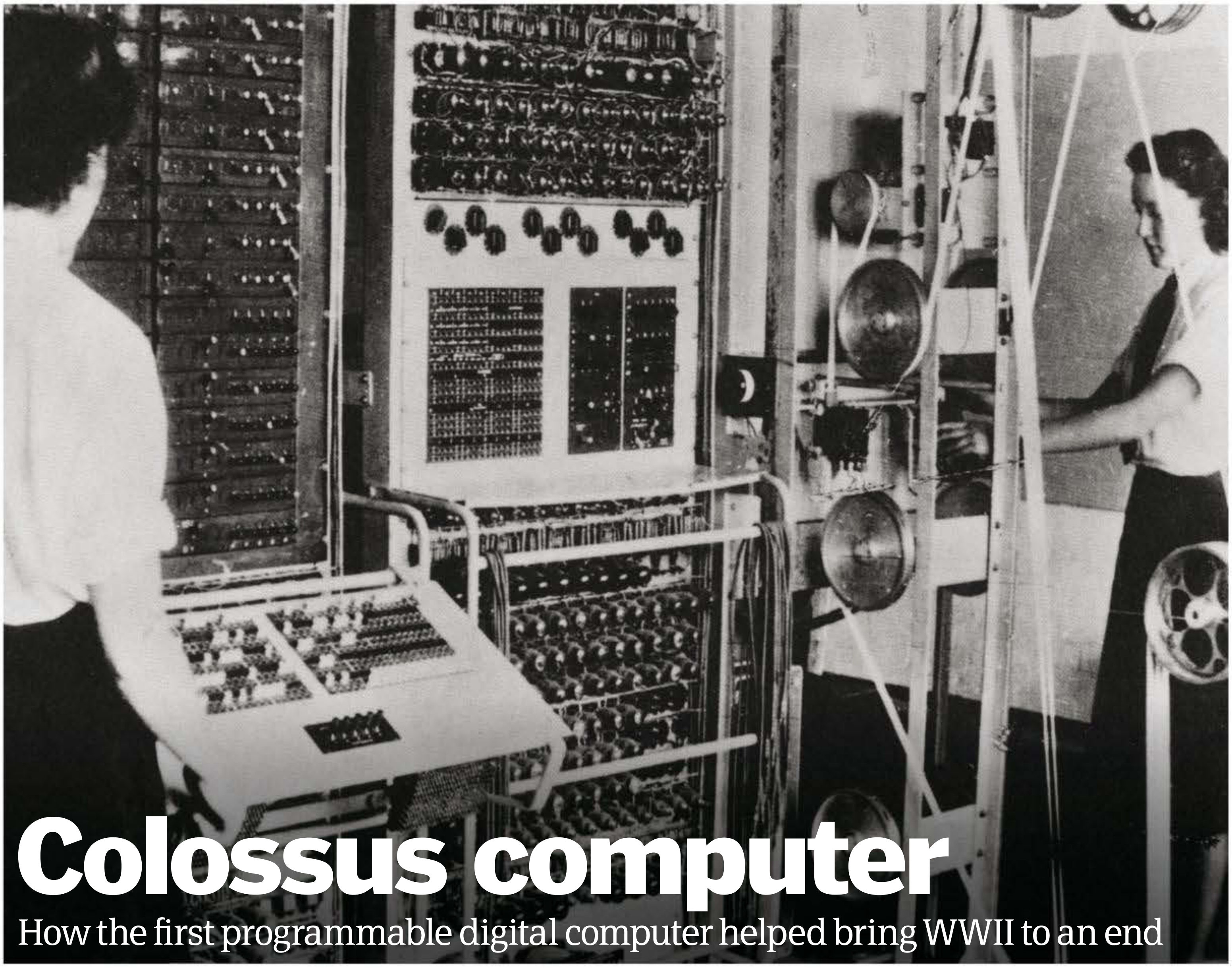


1. Mouthpiece
When a person spoke into the mouthpiece the acoustic vibrations shook the iron held within a stretched membrane in the transmitter which resulted in a variation of voltage, therefore converting acoustic energy into electrical energy.

2. Receiver
The electric charges are pulsed through the line and then converted back into acoustic energy at the other end.

3. Hook
A hook switch was later added to the device as was used to connect and disconnect the phone from the telephone network, and was installed when the first telephones were manufactured.

© DK Images



Colossus computer

How the first programmable digital computer helped bring WWII to an end

The Colossus computer was a machine used by the British intelligence service during World War II to analyse and decrypt teleprinter orders and messages enciphered with a Lorenz SZ40/42 encryption machine by the Nazi Germany High Command. The contents of the messages were of incredible value to the Allies, as they often contained key orders for German generals, including troop movements and tactics.

Prior to the German use of the Lorenz cipher, the Allies had successfully cracked their Enigma code and had for years held the ability to decode messages thanks to Alan Turing's electromechanical Bombe machine. The Lorenz cipher was much more complex, however, with the SZ40/42 enciphering a message by combining its characters with a keystream of characters generated by 12 mechanical pinwheels. As such, without knowing the key characters – ie the position of the pinwheels – no decryption could take place.

The Colossus solved this issue by finding the Lorenz key settings, rather than actually decoding the message – the latter part done manually by cryptologists. The computerised process involved the Colossus analysing the inputted encoded message's characters and then counting a statistic based on a programmable logic function (such as whether an individual character is true or false). By analysing a cipher text in this way a number of times, the initial position of the Lorenz machine's 12 pinwheels could be determined and the keystream established.

Historically, the Colossus proved to be a colossal success, with the Allies decoding many war-changing messages throughout 1944 and 1945 and the generated intelligence used to counter the Nazis' movements in Europe. In addition, after the war, the technological advancements in computing brought about by Colossus led to Britain becoming a pioneering centre for computer science.

A colossal reconstruction

As part of the transformation of Bletchley Park into a museum, a fully functional replica of the Mark 2 Colossus was completed in 2007 by a team of engineers led by electrical engineer Tony Sale. Unfortunately, this was nowhere near as simple as six decades' worth of technological advancement since the war might make you think, with many blueprints and original hardware being destroyed after WWII, leaving those responsible for its reconstruction severely lacking in workable information.

Luckily though, after a dedicated research campaign, many of the Bletchley team's original notebooks were acquired, which when collated delivered a surprising amount of information. As such, by using the notebooks and consulting several original members of the Bletchley team, including the designer of the Colossus's optical tape reader – Dr Arnold Lynch – the reconstruction was completed successfully and is today situated in exactly the same position of the original Colossus at Bletchley Park, where it can be used to crack codes once more.

DID YOU KNOW? *The Colossus was not made public knowledge until the 1970s due to the Official Secrets Act*

A sculpture to commemorate Flowers, with his son (left)

Flowers in focus

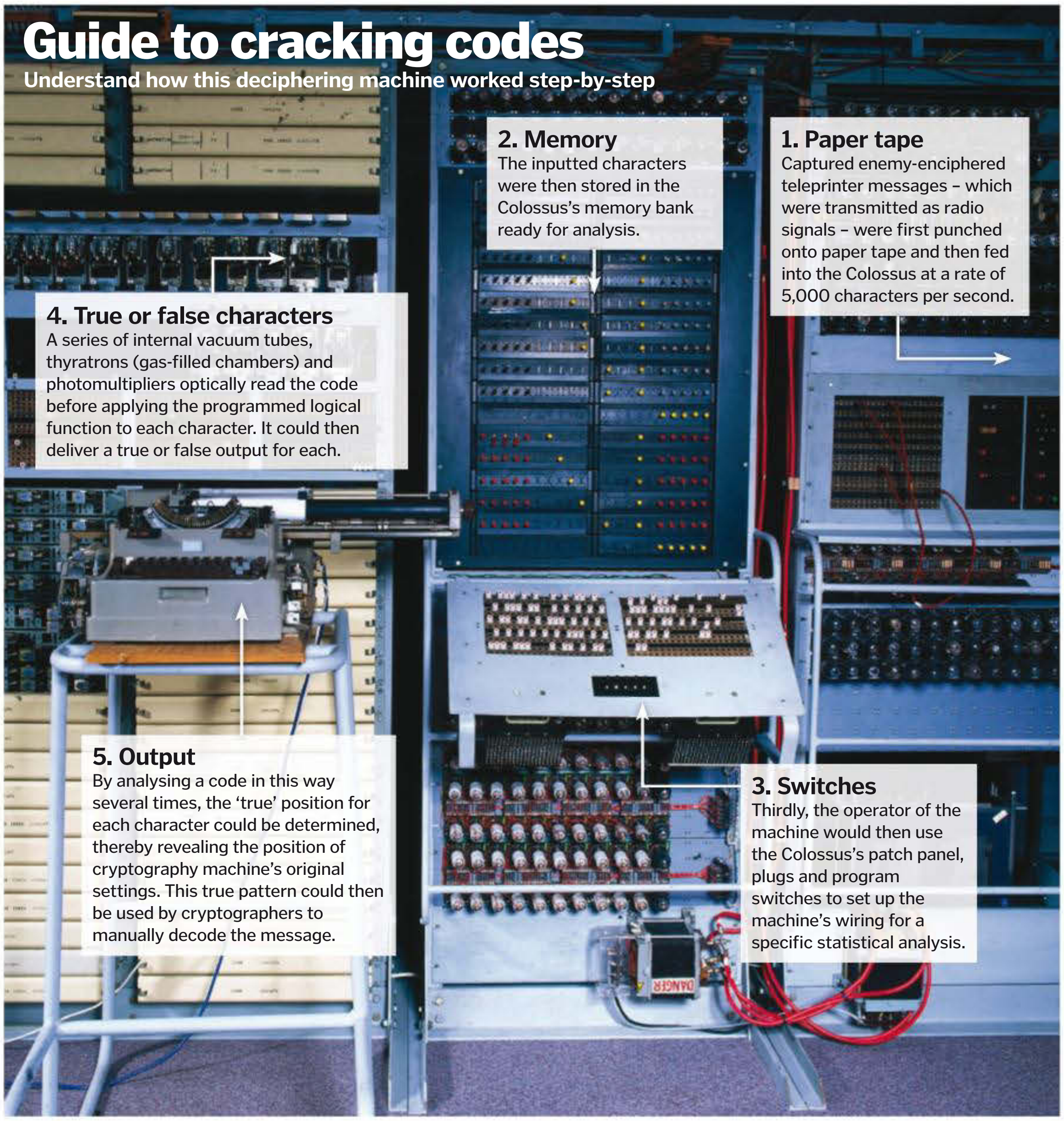
Thomas (Tommy) Flowers was the British engineer behind the revolutionary design and construction of the Colossus computer. After graduating from the University of London with a degree in electrical engineering, Flowers went on to join the telecommunications branch of the General Post Office, where he explored the use of electronics for telephone exchanges.

Off the back of this work, Flowers was invited to help code-breaking expert Alan Turing to build a machine that could help automate part of the cryptanalysis of Nazi Germany's Lorenz cipher – a high-level cipher used to communicate important orders from the high command.

By 1943 Flowers had built the Colossus, and soon after received funding to create a second improved variant, which went into active service in June 1944. Despite his key role in helping the Allies to victory, Flowers could not talk about his work for decades after the war as he was sworn to secrecy.

Guide to cracking codes

Understand how this deciphering machine worked step-by-step



1. Paper tape

Captured enemy-enciphered teleprinter messages – which were transmitted as radio signals – were first punched onto paper tape and then fed into the Colossus at a rate of 5,000 characters per second.

2. Memory

The inputted characters were then stored in the Colossus's memory bank ready for analysis.

3. Switches

Thirdly, the operator of the machine would then use the Colossus's patch panel, plugs and program switches to set up the machine's wiring for a specific statistical analysis.

4. True or false characters

A series of internal vacuum tubes, thyratrons (gas-filled chambers) and photomultipliers optically read the code before applying the programmed logical function to each character. It could then deliver a true or false output for each.

5. Output

By analysing a code in this way several times, the 'true' position for each character could be determined, thereby revealing the position of cryptography machine's original settings. This true pattern could then be used by cryptographers to manually decode the message.

In 1993 Bletchley Park was re-opened as a museum devoted to code breakers

Bletchley's role in WWII

Bletchley Park was the British government's main decryption headquarters throughout World War II. Located in Milton Keynes, Buckinghamshire, England, Bletchley was a top-secret facility for Allied communications, with a diverse team of engineers, electricians and mathematicians working manually – and later with the help of decryption machines – to break the various enemy codes used to disguise orders and private communiqués.

Among the many decoders – also known as cryptanalysts – working at Bletchley, Alan Turing became by far the most famous, with his work in breaking the Enigma and then Lorenz codes earning him the nickname the 'Father of Computer Science'. Indeed, between them Turing, Flowers and the rest of the Bletchley team's efforts arguably were crucial to the Allies' eventual victory in 1945, with the intelligence gathered by them – intel which was code-named 'Ultra' – speculated by some to have shortened the war by up to four years.

Today Bletchley Park is run by the Bletchley Park Trust, which maintains the estate as a museum and tourist attraction, with thousands of people visiting the site every year. Among the Trust's many activities is the reconstruction of many of the machines that helped to break the Axis codes – as discussed in more detail in 'A colossal reconstruction' opposite.

After WWII Alan Turing went on to advance our knowledge of computers and artificial intelligence even further

> *"Bletchley Park was the main decryption headquarters throughout World War II"*

© Getty; Alamy; BT

Rack-and-pinion railways

How did these unique transit systems help hefty locomotives scale steeper mountain slopes than ever before?

A rack-and-pinion railway (also known as a cog railway) was one that employed a toothed track. The addition of the toothed rail – which was usually located centrally between the two running rails – enabled locomotives to traverse steep gradients over seven per cent, which remains to this day the maximum limit for standard adhesion-based railways.

Core to the operation of each rack-and-pinion system was the engagement of the locomotive's circular gears onto the linear rack. The rack and pinion therefore was essentially a means of converting the rotational energy generated by the train's powerplant into linear motion on the rack. As both the rack-and-pinion gears had teeth, the system also acted as an additional form of adhesion to the track, with the inter-meshing teeth holding the vehicle in place when not in motion.

Due to the primary form of power traditionally being steam, for rack-and-pinion systems to work the trains needed to be considerably adjusted. This modification stretched from the undercarriage of the train (so pinions could be installed) to the tilting of its boiler, cab and superstructure.

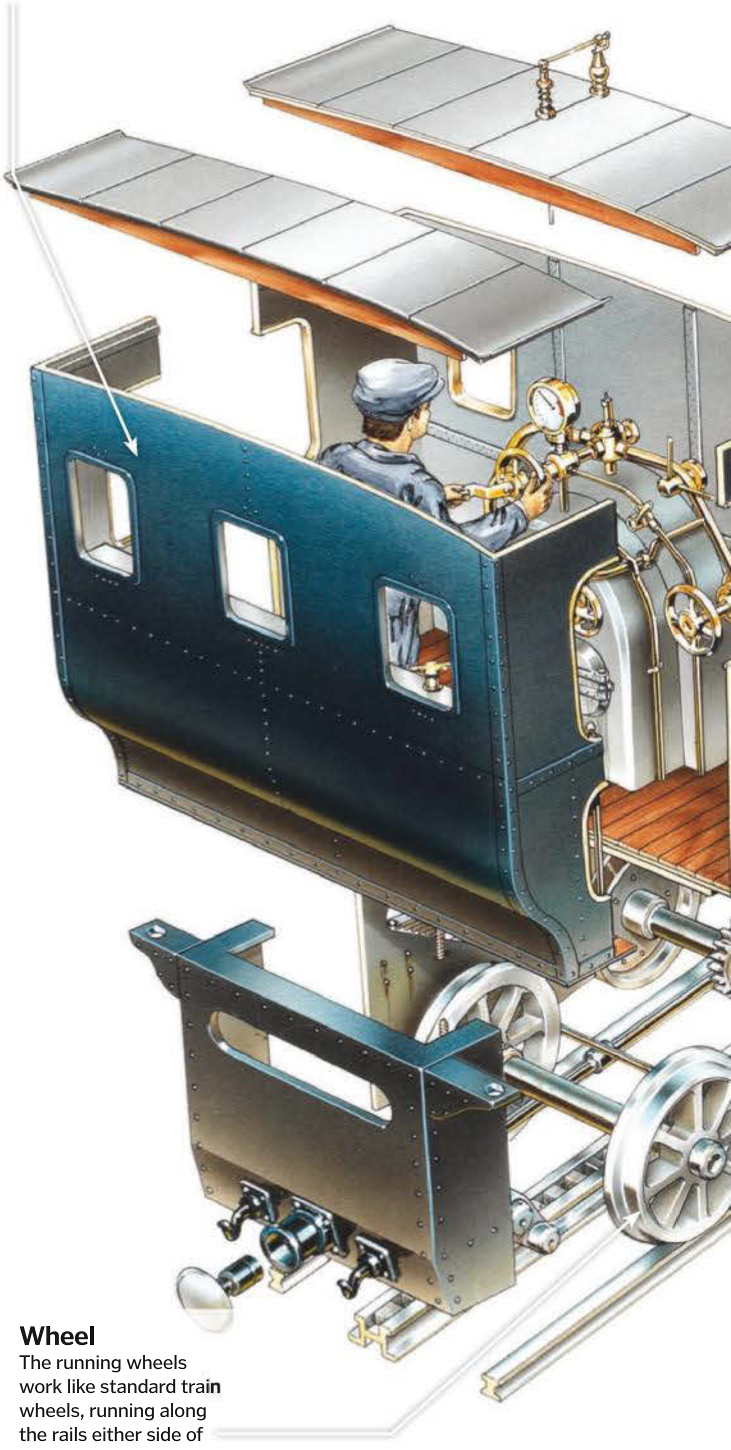
Tilting was necessary as steam engine boilers require water to cover the boiler tubes and firebox at all times to maintain stability – something that is nigh-on impossible to achieve if the train isn't level. As such, cog railway locomotives would lean in towards the track to counter the terrain's gradient.

Today, while rare, rack-and-pinion systems are still in operation worldwide, albeit with a mix of steam engines and diesel/electric locomotives. One of the most famous is the Mount Washington Cog Railway, which we look at more closely in the boxout opposite.

A rack-and-pinion railway built with a Strub system in rural Italy, 1920

Rack and roll

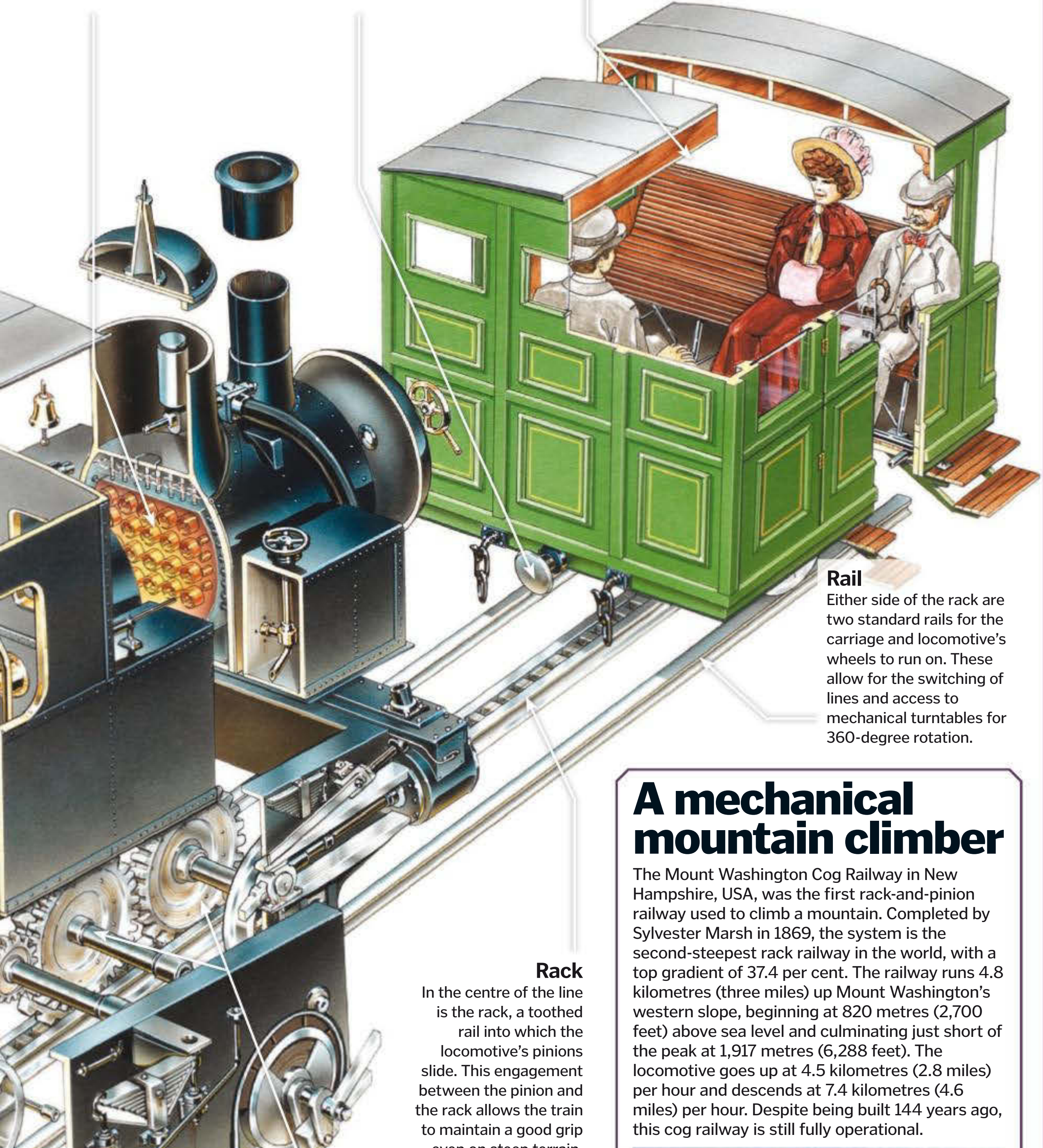
Understand the anatomy of a rack-and-pinion locomotive now with our cutaway illustration



Cabin
To the rear of the engine and carriage is the cabin. From here the driver controls the steam boiler and the engagement of the pinion gears.

Wheel
The running wheels work like standard train wheels, running along the rails either side of the central rack.

DID YOU KNOW? *The first rack-and-pinion railway was introduced in West Yorkshire, England, in 1812*



Engine
Older cog railways would use steam engines to provide the power to drive the pinion gears. As with the cab, the engine is tilted forward so it's level during operation.

Buffer
Unlike standard adhesion trains, rack-and-pinion systems don't tend to attach the carriage to the locomotive with a linkage. Instead, the carriage is simply pushed with the locomotive's buffers.

Carriage
Passengers sit in a covered wooden carriage. Due to the slow nature of the system, larger-than-standard windows are often installed that offer panoramic views.

Rail
Either side of the rack are two standard rails for the carriage and locomotive's wheels to run on. These allow for the switching of lines and access to mechanical turntables for 360-degree rotation.

Rack
In the centre of the line is the rack, a toothed rail into which the locomotive's pinions slide. This engagement between the pinion and the rack allows the train to maintain a good grip even on steep terrain.

Pinion gears
Mounted to the locomotive's undercarriage is a series of circular, teethed gears. As these rotate, driven by the engine, the teeth slot into the recesses in the rack, helping haul the train along.

A mechanical mountain climber

The Mount Washington Cog Railway in New Hampshire, USA, was the first rack-and-pinion railway used to climb a mountain. Completed by Sylvester Marsh in 1869, the system is the second-steepest rack railway in the world, with a top gradient of 37.4 per cent. The railway runs 4.8 kilometres (three miles) up Mount Washington's western slope, beginning at 820 metres (2,700 feet) above sea level and culminating just short of the peak at 1,917 metres (6,288 feet). The locomotive goes up at 4.5 kilometres (2.8 miles) per hour and descends at 7.4 kilometres (4.6 miles) per hour. Despite being built 144 years ago, this cog railway is still fully operational.

Cog railway evolution

1 Marsh

Made famous by the Mount Washington Cog Railway, the Marsh system – invented by Sylvester Marsh in 1861 – used the locomotive's gear teeth like rollers, arranged in rungs between two 'L'-shaped wrought-iron rails.

2 Riggenbach

The 1863-made system created by inventor Niklaus Riggenbach used a ladder rack made from steel plates connected by regularly spaced rods. While effective, the fixed ladder rack was fairly complicated and expensive to build, so very few examples survive.

3 Abt

Carl Roman Abt improved the Riggenbach system in 1882 by using multiple solid bars with vertical teeth machined into them that were mounted centrally between the rails. This ensured the pinions on the wheels were in constant contact with the rack.

4 Locher

Eduard Locher's system designed in 1889 had gear teeth cut into the sides of the rails rather than the top, which were engaged by two cog wheels on the locomotive. This new system could work on steeper track gradients than anything prior.

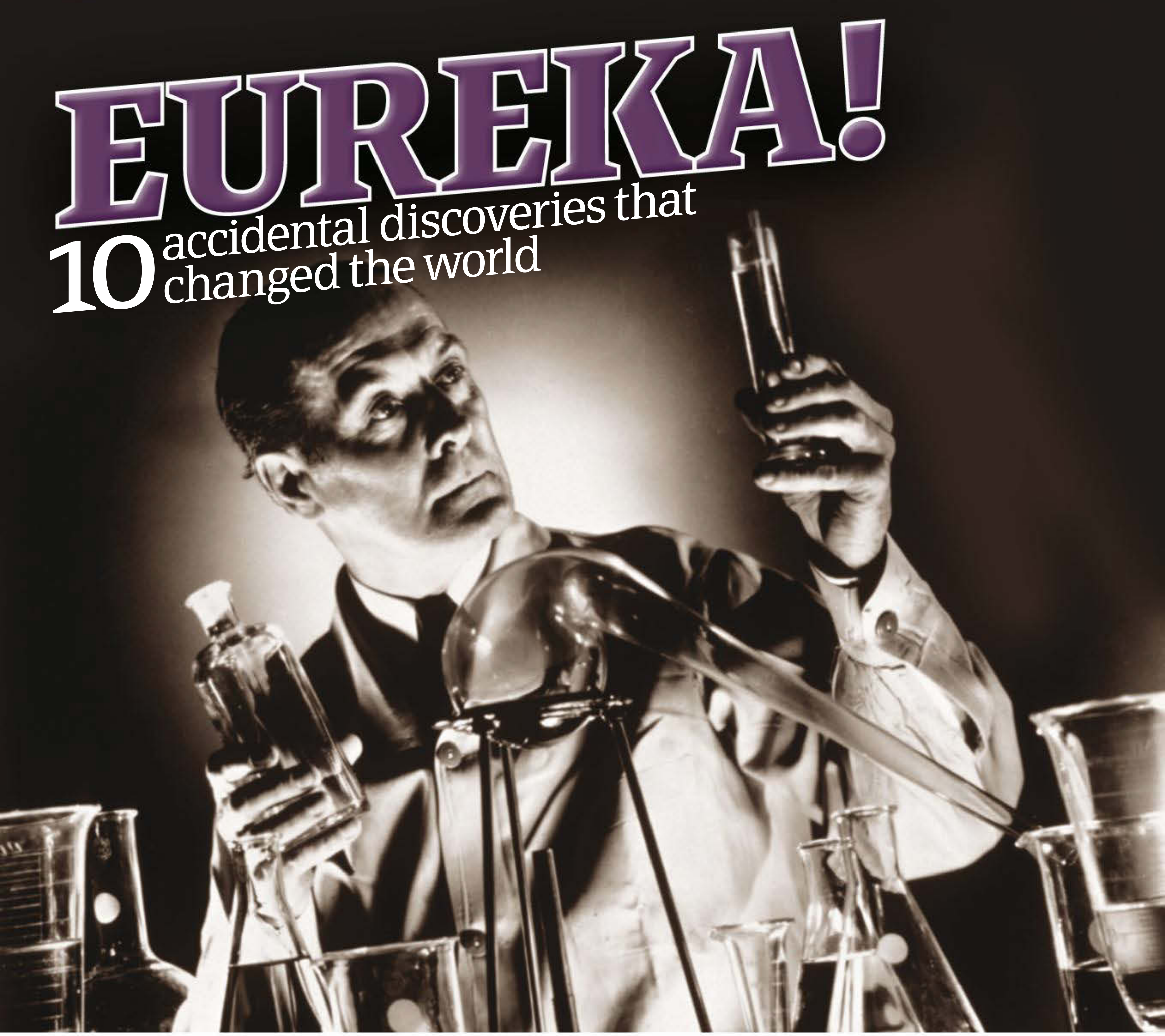
5 Strub

Invented by Emil Strub in 1896, the Strub system utilised a rolled flat-bottom rail with rack teeth machined into the head 100mm (4in) apart. The safety jaws installed on the locomotive gripped the underside of the head in order to prevent dangerous derailments.

© Alamy; Thinkstock

EUREKA!

10 accidental discoveries that changed the world



It's no secret that the best ideas often come to us when we least expect them to. For some it may be on the drive home from work or in the middle of the night, while others may have their lightbulb moments while taking 'time out' in the bathroom. The Ancient Greek mathematician Archimedes was in the latter group, having famously realised how to measure the volume of irregular objects while taking a bath. When he climbed in, the water level rose, and it occurred to him that the volume of water displaced must be equal to his own. How he maintained his reputation after running naked through the streets screaming 'Eureka', we're not sure!

It's not just ideas that can come to us by chance; sometimes it's a physical invention. While it's true that most of history's greatest discoveries were made after years of painstaking research, others happened completely by accident. Take the humble ice lolly, for example. Arguably a lifesaving invention during the hot summer months, it was initially the result of a failed attempt at making soda. In 1905, an 11-year-old boy called Frank Epperson had been trying to make himself a sugary beverage, but left his concoction outside overnight with the stirrer still in the cup. Being the middle of winter, the liquid froze, and in the morning Frank enjoyed a frozen treat on a stick. Eighteen years later, he realised the commercial possibilities his accidental invention could have, and he began selling them on California beaches.

So whether it's the result of a clumsy spill or a contaminated laboratory, accidental inventions are just a slapdash scientist away, as long as they are able to realise the potential. Naked celebrations are, of course, optional.

Penicillin

1

A contaminated experiment is any scientist's worst nightmare, but in the case of biologist Alexander Fleming, it would be his making. While studying the influenza virus, he accidentally left a petri dish out of the incubator while he was away on holiday. Upon returning, he discovered that the petri dish, in which he had been growing staphylococcus bacteria, had also begun to grow mould. When Fleming examined the dishes more closely he noticed that there was a ring around the mould where the bacteria had not grown. The 'mould juice' was actually penicillin, produced by the Penicillium mould that had contaminated the dish. Fleming later found that it was able to kill many different types of bacteria. It was two other scientists, Howard Florey and Ernst Chain, who turned penicillin into a drug, but without Fleming, antibiotics may never have been invented.

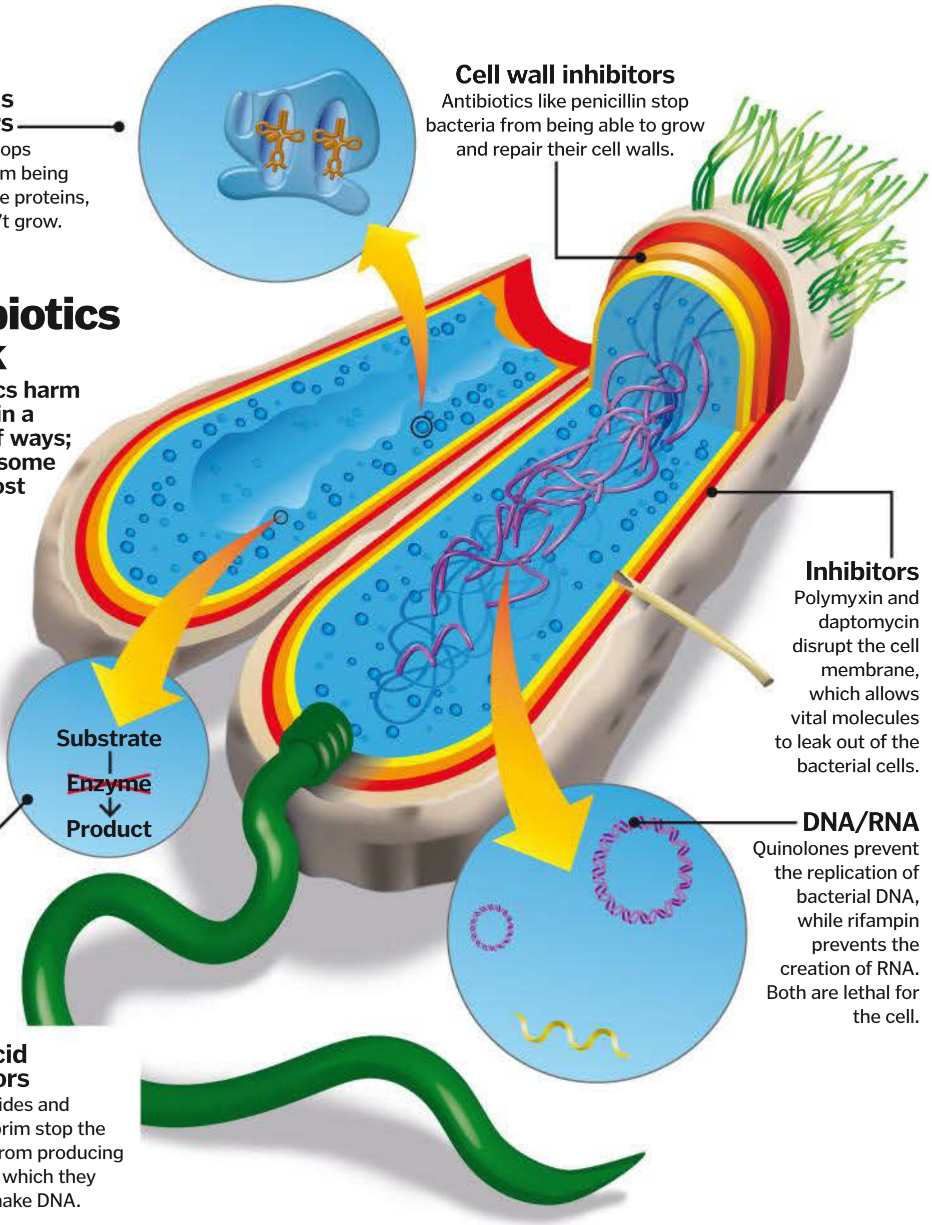
DISCOVERER CASE FILE

Sir Alexander Fleming

Born in Scotland in 1881, Fleming went on to study at St Mary's Hospital, London, where he completed a bachelor's degree in medicine. His accidental discovery of penicillin earned him a Nobel Prize, which he shared with Florey and Chain.

How antibiotics work

Antibiotics harm bacteria in a variety of ways; here are some of the most common



Protein synthesis inhibitors
This type stops bacteria from being able to make proteins, so they can't grow.

Cell wall inhibitors
Antibiotics like penicillin stop bacteria from being able to grow and repair their cell walls.

Inhibitors
Polymyxin and daptomycin disrupt the cell membrane, which allows vital molecules to leak out of the bacterial cells.

DNA/RNA
Quinolones prevent the replication of bacterial DNA, while rifampin prevents the creation of RNA. Both are lethal for the cell.

Folic acid inhibitors
Sulfonamides and trimethoprim stop the bacteria from producing folic acid, which they need to make DNA.

Plastics (Bakelite)

2

Throughout the 19th century, scientists tried desperately to solve the mystery of polymers – very large molecules that can be expanded and moulded. In 1870 an American inventor modified a naturally occurring polymer called cellulose to create an incredible new material called celluloid, which could be moulded or rolled when heated. But it would be another 40 years before the first wholly synthetic plastic was made. The discoverer, Leo Baekeland, had been experimenting with synthetic resins. After heating the liquid, he found that it produced a solidified matter, which was insoluble in solvents and did not soften when heated. He called it 'Bakelite', and it was soon used in the production of everything from electricals to jewellery.

Bakelite was used to make telephone casings because it was electrically nonconductive and heat-resistant

© Alamy; Thinkstock; WIKI

DISCOVERER CASE FILE

Leo Baekeland

A Belgian chemist born in 1863, Baekeland left his homeland for New York aged 23. Here he invented Velox photographic paper, which allowed developments under artificial light, before turning to plastics.

Microwave

3

Not only was the microwave discovered by accident, it was also discovered by a man who had not even completed high school. At the age of 12, Percy Spencer left education to work in a spool mill and was later hired to install electricity in a nearby paper mill. In the 1920s, Spencer began working as an engineer for Raytheon, a company that went on to improve radar technology for Allied forces in World War II. One day, he was stood in front of an active radar magnetron when he noticed the chocolate bar in his pocket had melted. He began testing the effects of magnetrons on other foods, and invented the first true microwave oven by attaching a high-density electromagnetic field generator to an enclosed metal box. The oven was a success, and in 1945 the company filed a patent for the first commercial microwave.

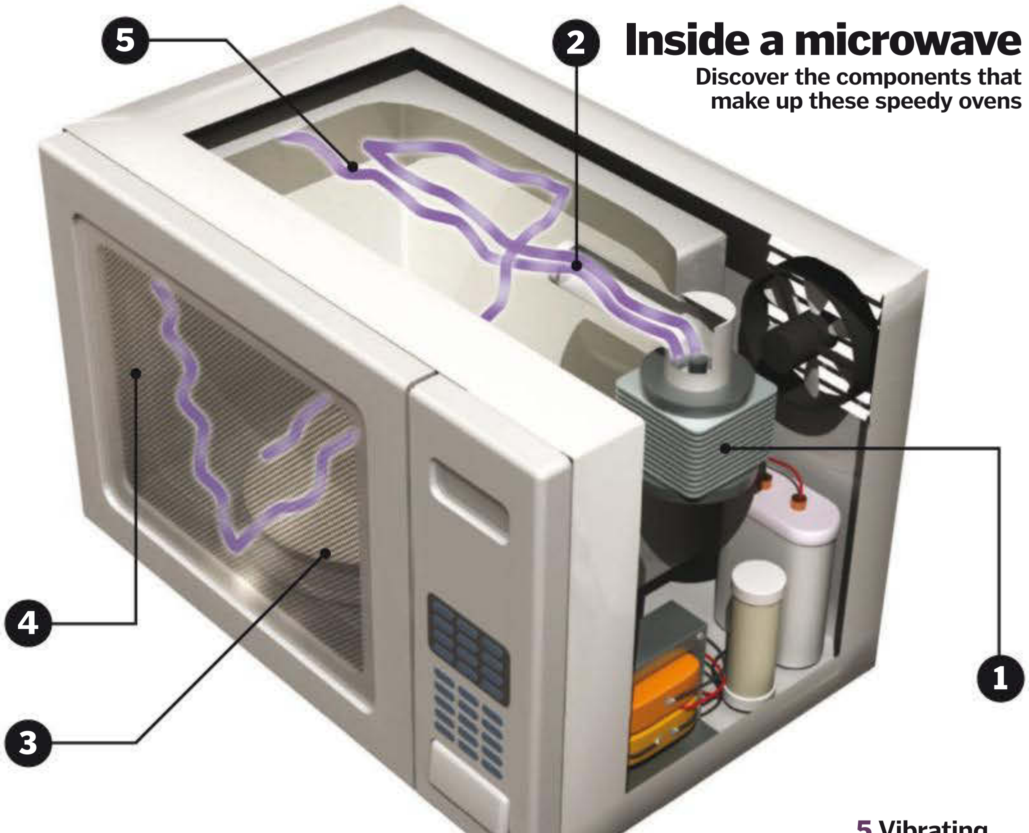
DISCOVERER CASE FILE

Percy Spencer

Born in 1893, at eighteen months old Spencer's father died and his mother left him in the care of his aunt and uncle. Despite his difficult start, he would become one of the world's most famed physicists.

Inside a microwave

Discover the components that make up these speedy ovens



1 Magnetron
When you hit start on a microwave, the magnetron takes electricity from the power outlet and converts it into high energy microwaves.

2 Wave guide
These waves are blasted into the food compartment through a channel called a wave guide.

3 Turntable
The food spins around on a turntable, allowing it to be cooked evenly.

4 Metal walls
The microwaves bounce off the reflective metal walls to hit the food from different angles.

5 Vibrating molecules
When the microwaves penetrate the food, they cause the molecules inside it to vibrate faster. This quickly heats the food up.

Artificial sweetener

4

The first artificial sweetener, saccharin, was discovered by a Russian chemist called Constantin Fahlberg. He had been experimenting with preservatives in his work, and while eating a bread roll, he noticed that it had been sweetened by the substance left on his hands. He went back to the lab and retraced his steps, until he was able to synthesise the sweetener in bulk.

DISCOVERER CASE FILE

Constantin Fahlberg

Fahlberg was initially hired to analyse the purity of sugar.

Süßstoff Saccharin
100 Schachteln zu 100 Tabletten
Deutsche Süßstoff-Gesellschaft m.b.H. Berlin W 35

Saccharin rose to popularity during World War II, when sugar became scarce

DURO
SUPER GLUE

Superglue

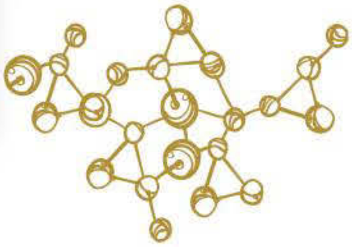
5

This super-sticky substance was discovered by accident – twice! Chemist Harry Coover had been attempting to make clear plastic gun sights for the Second World War, and one formulation he tested produced an extremely quick bonding adhesive. It was useless for his gun sights, though, and he forgot about it until almost ten years later, when he stumbled across it again while developing heat-resistant canopies for jet airplanes. This time he realised its potential, and the product was put on the market.

DISCOVERER CASE FILE

Harry Coover

Coover worked as a chemist for Eastman Kodak.



Coca-Cola

6

After being wounded in the American Civil War, pharmacist John Pemberton became addicted to morphine. Seeking an alternative, in 1886 he began experimenting with coca – the plant from which cocaine is derived. He eventually stirred up a fragrant, caramel-coloured liquid that he combined with carbonated water and put on sale for five cents a glass. The soda, named Coca-Cola, would become the world's fourth most valuable brand.

DISCOVERER CASE FILE

John Pemberton

Pemberton established a wholesale drug business.

Stainless steel

7

Steel has been forged for millennia, but it wasn't until 1913 that a metallurgist called Harry Brearley discovered a way to stop it rusting. He had been tasked with finding an erosion-resistant metal to prolong the life of gun barrels. Legend has it that as attempt after attempt failed, his pile of scrap metal grew bigger, and he later noticed that one of the scraps hadn't rusted like the others. He had invented stainless steel, and quickly saw its potential in the cutlery industry.

DISCOVERER CASE FILE

Harry Brearley

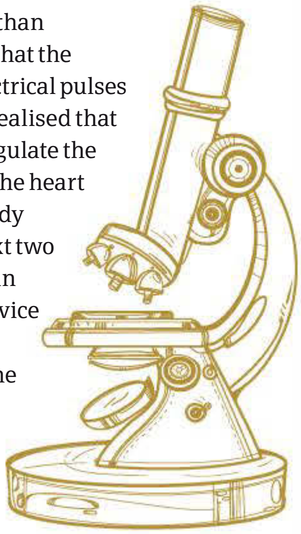
Brearley was lead researcher at Brown Firth in 1908.

The pinnacle of New York's Chrysler Building is clad with non-rusting stainless steel

Pacemaker

8

Pacemakers have existed in a very rudimentary form since the 19th century, when it was discovered that electrical impulses could be used to provoke a heartbeat. However, the devices that followed were large and bulky and had to be plugged into a mains current, putting the patient at risk of electrocution. It wasn't until 1960 that battery-powered implantable pacemakers came into use, having been invented four years previously. Electrical engineer Wilson Greatbatch was working on a heart-rhythm recorder when he added the wrong size of resistor to the circuitry. Rather than recording, he found that the device produced electrical pulses instead. He quickly realised that it could be used to regulate the electrical activity of the heart and guarantee a steady rhythm. Over the next two years, he succeeded in miniaturising the device and making it safe from bodily fluids. The first patient, a 77-year-old man, went on to live for a further 18 months.



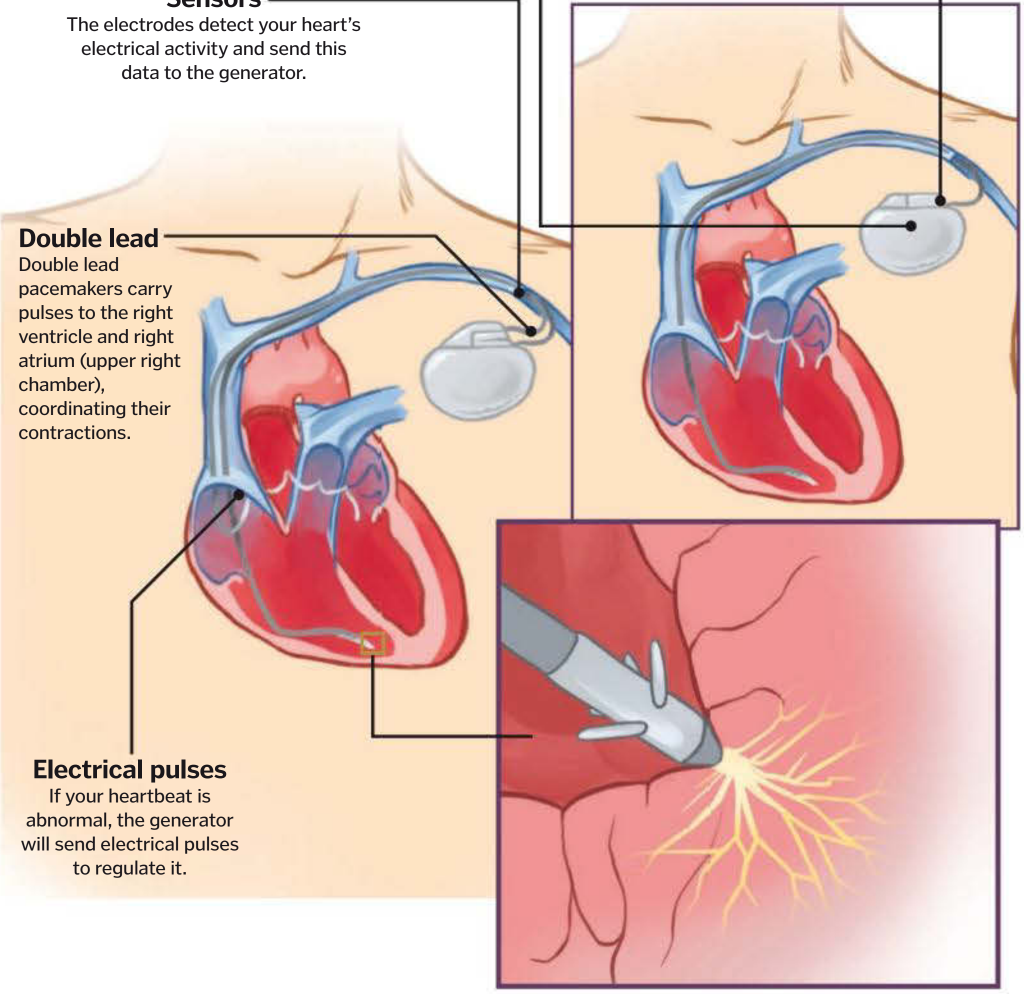
DISCOVERER CASE FILE

Wilson Greatbatch

The American engineer and inventor was born in New York in 1919, and served in World War II before completing a degree in electrical engineering. By the time of his death in 2011, he held over 325 patents.

How a pacemaker works

Discover how these amazing pieces of tech can keep our hearts beating



Composition
A pacemaker consists of a battery, a generator and a series of wires with sensors (electrodes) at their tips.

Single lead
Single lead pacemakers usually carry pulses from the generator to the right ventricle (the lower right chamber of the heart).

Sensors
The electrodes detect your heart's electrical activity and send this data to the generator.

Double lead
Double lead pacemakers carry pulses to the right ventricle and right atrium (upper right chamber), coordinating their contractions.

Electrical pulses
If your heartbeat is abnormal, the generator will send electrical pulses to regulate it.

Teflon

9

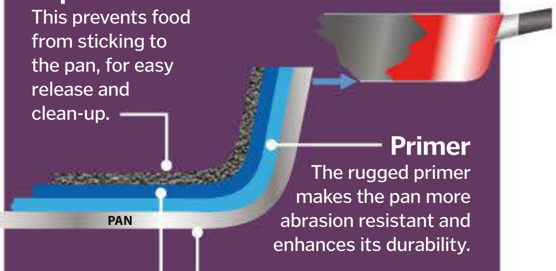
The non-stick substance found on frying pans was inadvertently invented by a man called Dr Roy Plunkett. He had been trying to synthesise a non-toxic alternative to refrigerants like sulphur dioxide and ammonia, and was experimenting with tetrafluoroethylene (TFE). After storing the gas in cylinders, he opened one to discover that it had polymerised into a waxy white powder that was extremely sticky and had a very high melting point. Three years later, the substance, which was named Teflon, was patented.

DISCOVERER CASE FILE

Roy Plunkett
Plunkett received the John Scott Medal for the "comfort of humankind".

Protecting a pan

Peel back the layers to find out what makes modern frying pans so practical



Topcoat
This prevents food from sticking to the pan, for easy release and clean-up.

Primer
The rugged primer makes the pan more abrasion resistant and enhances its durability.

Midcoat
A tough midcoat provides resistance to scratches and abrasions.

Base
The hard base is usually made from aluminium or stainless steel.

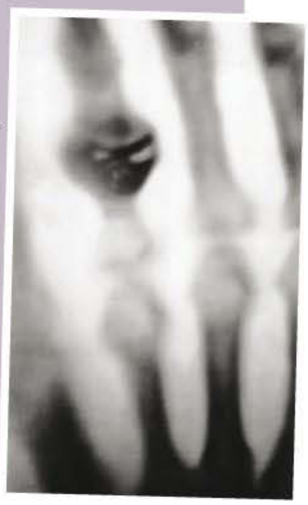
X-Rays

10

It was while German physicist Wilhelm Röentgen was investigating the effects of cathode ray tubes that he made a curious discovery. During an 1895 experiment, he evacuated the tube of all air and filled it with gas before passing an electric current through it. Despite it being covered with black paper, he noticed that a screen several feet away was illuminated by the invisible rays, which he named 'X' to indicate the unknown. They were later found to pass through human tissue, allowing for the imaging of bones.

DISCOVERER CASE FILE

Wilhelm Röentgen
Born the only child of a cloth merchant in 1845, Röentgen studied mechanical engineering.



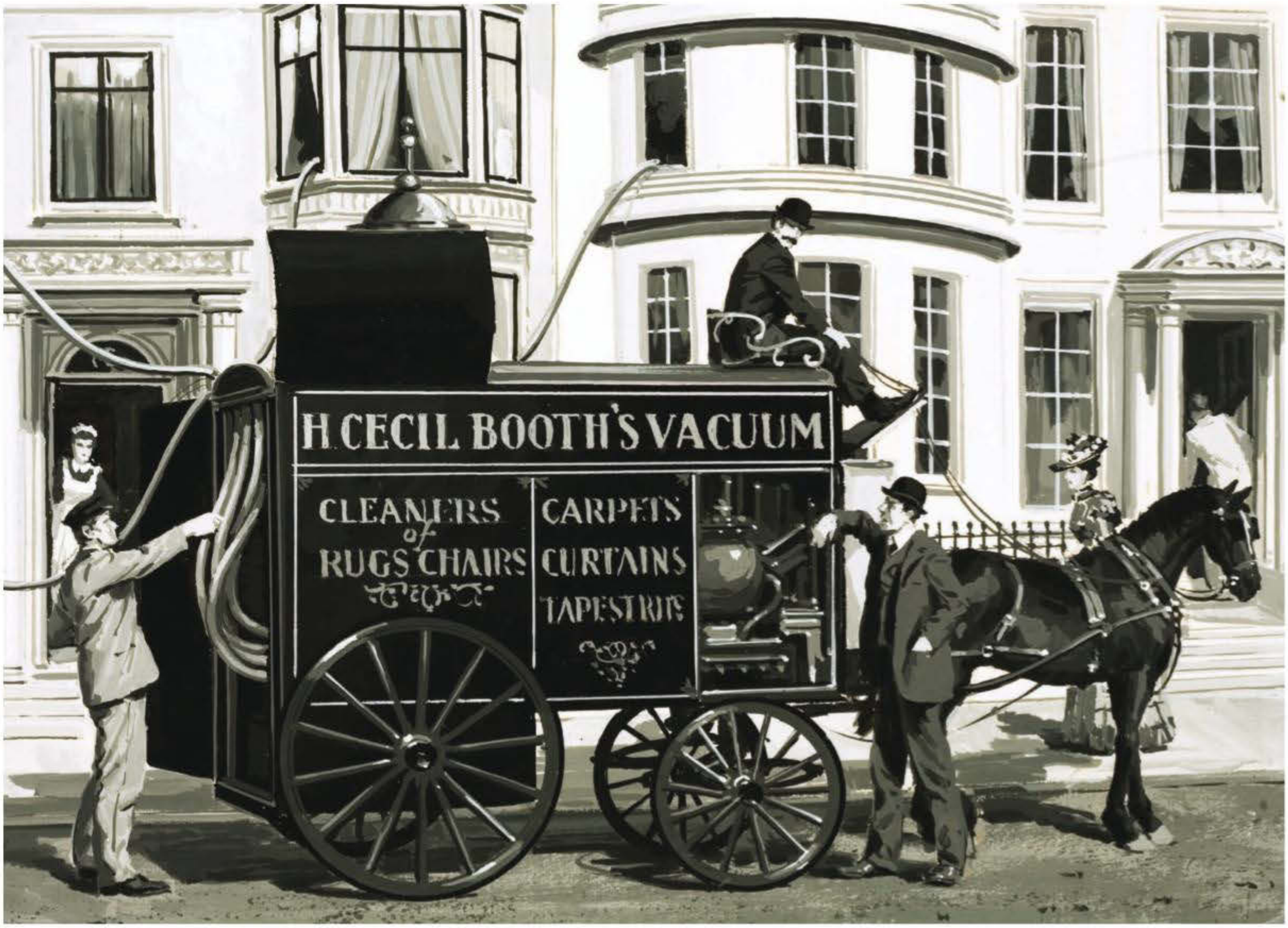
Röentgen took this radiograph of his wife's left hand

© Alamy; Thinkstock; WIKI

The first vacuum cleaner

How this horse-drawn vacuum cleaned Victorian houses

British engineer Hubert Cecil Booth patented the motorised vacuum cleaner in 1901. Far from the slender, high-tech pieces of equipment we have nowadays, this vacuum cleaner was so cumbersome it had to be drawn by a horse and cart. Because most Victorian houses didn't have electricity, Booth's machine had to get its power from coal or oil. It would park outside a house and a 244-metre (800-foot) long hose would snake in through the windows and the oil-powered engine would burst into life. It sucked the dirt into a filter, ridding homes of years and years of accumulated dust. Far too big for everyday use, Booth successfully marketed it as a hired service and was even asked to clean the ceremonial carpet for King Edward VII's coronation in 1902!



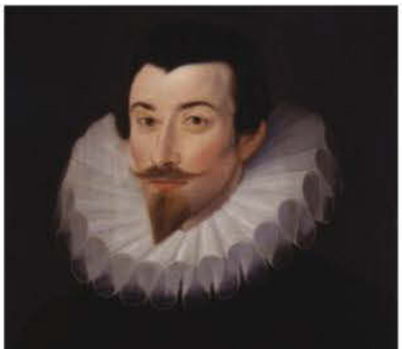
Who invented the toilet?

Meet the man responsible for the first modern flushing toilet

Contrary to popular belief, the first man to invent the flushing toilet was not Thomas Crapper. It was actually a member of Queen Elizabeth I's court, Sir John Harrington.

First described in 1596, Harrington's device was composed of a deep oval bowl, which was made waterproof with a mixture of pitch, resin and wax. This was flushed with water released from a cistern above the toilet, on the next floor or in the roof.

In spite of this breakthrough, it took more than 200 years for the flushing toilet to catch on. Advances in technology that accompanied the Industrial Revolution helped to spur on the toilet's development, as did the invention of the 'S-trap' in 1775. Still present in modern toilets, this S-shaped pipe allows standing water to seal off the bowl, preventing gases from the sewer rising up and escaping into your bathroom.



One of Queen Elizabeth I's godsons, Sir John Harrington built the first flushing toilet in his own home

© Look and Learn; Dreamstime

DID YOU KNOW? *High-tech life-preserving caskets are still being designed today, featuring intercoms and heartrate monitors*

How are bronze statues cast?

Explore the complex process behind this centuries-old art

The first step in the casting of a bronze statue is to create a replica of the piece out of wood or clay. Secondly a lubricant such as oil is used to coat the statue followed by a thick layer of silicone rubber. After the rubber has hardened – a process that can take 24 hours – the coating can be removed from the replica, leaving a detailed mould.

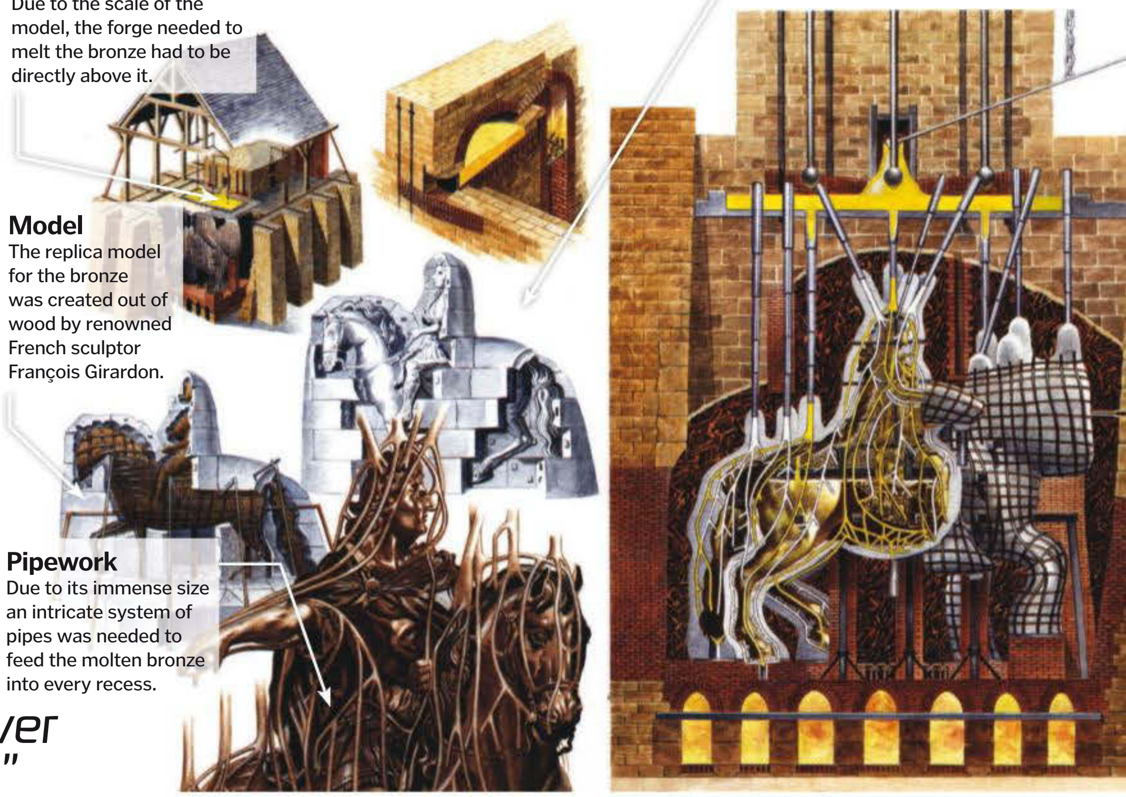
Next, the mould is filled with hot wax. After being left to cool, the mould is taken off to leave a wax sculpture. After attaching the wax model to a device called a screw that channels molten bronze via a series of fine channels, the mould is dipped into a ceramic solution and covered with powdered silicon to strengthen it.

The internal wax mould is then melted in a steam oven, while the ceramic one is fired to provide the final mould. Bronze is heated to over 2,000 degrees Celsius (3,630 degrees Fahrenheit) prior to being poured into the mould, solidifying in 30 or so minutes. Lastly the ceramic layer is chipped and sandblasted away to reveal the bronze statue within.

> *"Bronze is heated to over 2,000 degrees Celsius"*

Making Louis XIV on Horseback

See how this famous statue of the French king was created



Forge
Due to the scale of the model, the forge needed to melt the bronze had to be directly above it.

Model
The replica model for the bronze was created out of wood by renowned French sculptor François Girardon.

Pipework
Due to its immense size an intricate system of pipes was needed to feed the molten bronze into every recess.

Stone casing
The replica and castings were protected and structurally reinforced by a thick layer of stone.

What are life-preserving coffins?

How did this odd casket save anyone buried alive?

Very much a historical oddity, the life-preserving coffin was a special burial casket designed by Christian Henry Eisenbrandt in 1843 to allow those mistakenly buried alive to safely get out.

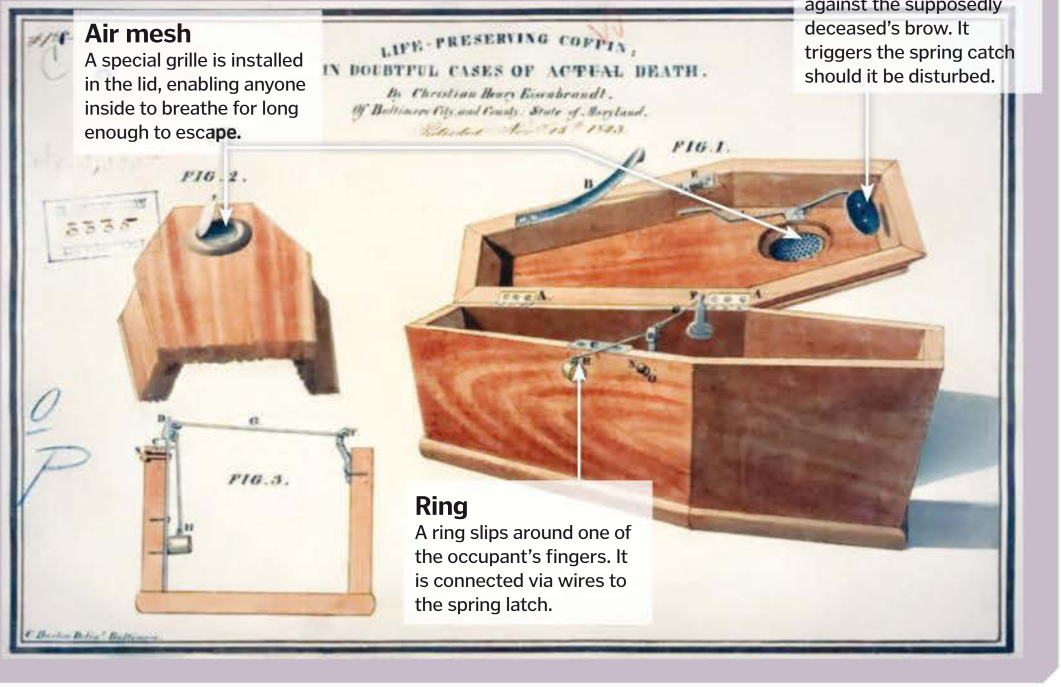
The system works by fitting the typical hinged lid with a series of levers and springs, which activate via motion-detecting devices in the coffin, ultimately releasing the latch.

Any motion is detected through two mechanisms: a ring slipped around the occupant's finger and a metal head plate. Both are connected by wires to the coffin's opening mechanism, with the slightest movement triggering the lid catch.

In addition to the opening mechanism, the life-preserving coffin also features a mesh in its lid which would supposedly provide a limited supply of air post-burial.

Back from the dead

Check out the key components of this unusual Victorian coffin



Air mesh
A special grille is installed in the lid, enabling anyone inside to breathe for long enough to escape.

Head plate
A head plate is placed against the supposedly deceased's brow. It triggers the spring catch should it be disturbed.

Ring
A ring slips around one of the occupant's fingers. It is connected via wires to the spring latch.

© Corbis; Getty

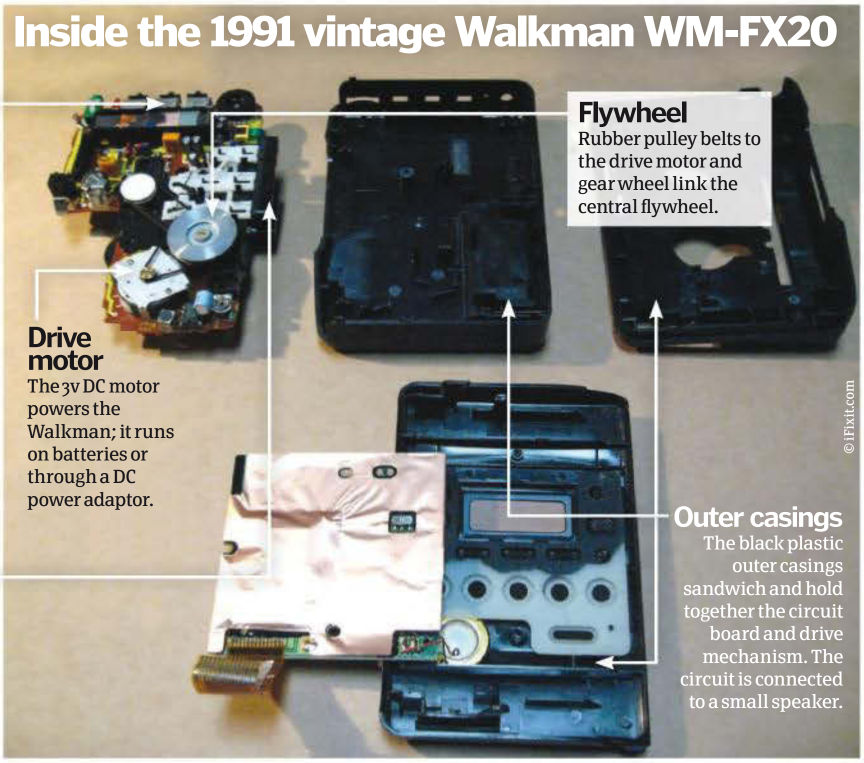
The Sony Walkman

Inside the world's first commercial portable and personal stereo cassette player

For 20 years after its introduction in 1979, the Walkman dominated the personal stereo market. The first Walkman (TPS-L2) had two mini headphone jacks that enabled two people to simultaneously listen to it through Sony's new lightweight 50-gram (1.8-ounce) MDR-3L2 headphones.

The blue and silver metal-cased unit measured 88 x 133.5 x 29mm (3.5 x 5.25 x 1.15in), weighed only 391 grams (13.8 ounces) and was powered by two AA batteries, making it light, compact and easily portable. It could also be powered by a 3v DC adaptor (which wasn't supplied with the Walkman).

It contained a stereo tape head that played standard compact audiocassette tapes at a frequency response rate of 40Hz-12kHz. 300 to 500 different Walkman models have been produced that have since included new media formats like MiniDiscs and CDs, but it was only in 2010 that the cassette-based Walkman ceased production in Japan. New rivals like the introduction of Apple's iPod digital music player in 2001 and the increasing sophistication of mobile phones helped put the Walkman brand in the shade.



Inside the 1991 vintage Walkman WM-FX20

Additional controls
There is one headphone socket and a rotating volume control. Three push buttons change the mode from tape deck to radio, normal to metal audiocassette tape, and FM to AM radio stations. It also includes an LCD digital alarm clock.

Controls
There are three push-button Play, Rewind and Fast-Forward controls. Next to them is the Stop/Eject button, which opens the front panel to insert or remove an audiocassette from the machine.

Drive motor
The 3v DC motor powers the Walkman; it runs on batteries or through a DC power adaptor.

Flywheel
Rubber pulley belts to the drive motor and gear wheel link the central flywheel.

Outer casings
The black plastic outer casings sandwich and hold together the circuit board and drive mechanism. The circuit is connected to a small speaker.

© iFixit.com

Hearing aid evolution

Find out why modern electronic hearing aids were made possible by Alexander Graham Bell and his telephone

Up until the late-19th century, hearing aids were little more than just passive tubes that relied entirely upon capturing sound waves and funnelling them as much as possible towards the ear.

It wasn't until the invention of the telephone, which contained technology capable of converting sound energy into an electrical signal, that advances in hearing aid devices were made possible. This could then be amplified and sent to a speaker positioned near, or inside, the user's ear.

The key piece of tech was the carbon transmitter, invented independently by Thomas Edison, Emile Berliner and David Hughes, but Edison was awarded the first patent. The transmitter contained carbon granules, which reduce their electrical resistance when compressed by the pressure generated by sound waves. Miller Reese Hutchison used this device in 1898 to create the Akouphone, the first electric hearing aid.

Carbon transmitter hearing aids were very bulky, but the invention of smaller amplifiers – first the vacuum tube and later on the transistor – allowed for increasingly portable devices. Transistors were not only smaller, but they also consumed less power, meaning battery size could be reduced, making hearing aids ever-more practical for users.

The development of computers – particularly microprocessors – allowed hearing aids to be digitised. This enabled the incoming sound to be processed before being sent to the speaker, allowing the signal to be separated, with individual frequencies modulated to boost weak sounds and adjustments made according to incoming pitch and volume.

Hearing aids have developed from basic trumpets to digital devices tiny enough to fit inside the ear

© Alamy

Direct to the brain

Today's hearing aid technology is more advanced than ever. A cochlear implant is commonly used to deliver electrical signals through the cochlea to the auditory nerve. But if the nerve itself is damaged, auditory brainstem implants may be used instead. The cochlear nucleus is the area of the brain responsible for processing signals from the auditory nerve and can be stimulated artificially with electrodes. A processor is worn on the outside of the ear and transmits a signal to a receiver, implanted just beneath the skin. The receiver is connected to a silicon-coated implant array, which terminates on the brainstem, directly stimulating the nerves so sound can be perceived.

DID YOU KNOW? *More than 8 million refrigerators are sold annually in the United States*

How did the first electric refrigerators work?

Often taken for granted today, once refrigerators were a groundbreaking and luxury appliance

Back in the Twenties, one electric refrigeration company dominated the market: Kelvinator. Its wooden cold box/compressor combo cost $714 (nearly $9,800/£6,100 today) – way beyond the pocket of the average household. So, with the goal of bringing more affordable refrigerators to the masses, General Electric ploughed $18 million into making the GE 'Monitor-top' fridge.

They were called Monitor-tops because the cabinet was all steel and the condenser was sealed in a cylindrical enclosure on top, which made it look like the turret from a 19th-century ironclad warship – the USS Monitor.

These refrigeration units worked under the same principles as modern fridges. By using a compressor, a circulating refrigerant was transformed from vapour into a liquid and cooled to near-room temperature under pressure, before being released back into circulation. The sudden change in pressure caused the refrigerant to turn into a vapour again, which had to draw heat from the air inside the cabinet, ultimately cooling it.

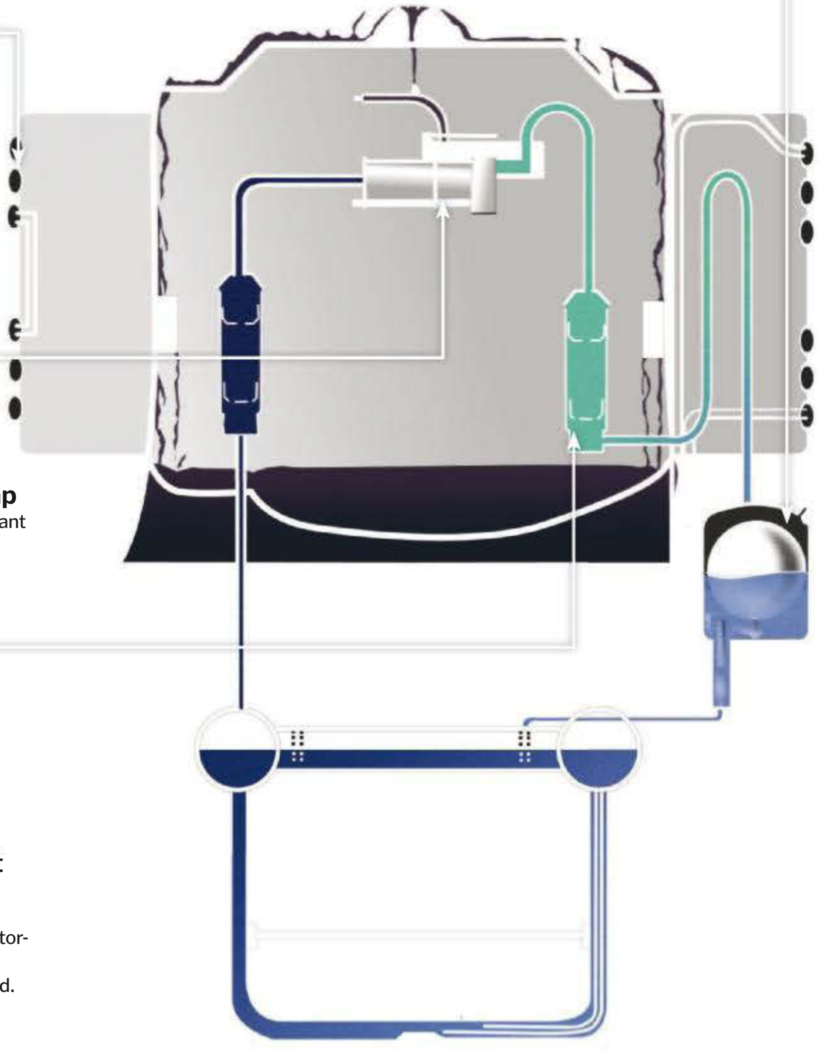
Several models of the Monitor-top were made, including two and three-door units, but the most popular was the single-door variant, which originally sold for $300 in 1927.

Toxic origins

Today, the inert tetrafluoroethane gas R134a is commonly used in fridges and freezers, but in the Twenties refrigerants like sulphur dioxide, methyl formate and methyl chloride were used. These are quite toxic: sulphur dioxide causes burns on contact and can damage vision, methyl formate is highly flammable, while methyl chloride, or chloromethane, can cause dizziness, nausea and even seizures at high concentrations. These nastier chemical refrigerants were replaced by Freon, a relatively harmless gas that, nevertheless, was banned in the production of new fridges in 1990 over concerns about CFCs' effect on the ozone layer. Monitor-top fridges have become quite collectable now, the steel build ensuring many have survived for nearly a century. They are usually converted, with the dangerous gases removed and a modern compressor system installed to be eco-friendly.

Inside a Monitor-top fridge

Discover the major components that made up one of the first commercial refrigerators



Heat-exchanging pipes
The liquid refrigerant, warm from compression, is passed around a series of pipes and cooled to room temperature.

Compressor pump
This pushes the refrigerant around the unit and compresses the refrigeration vapour.

Liquid refrigerant
The compressor applies pressure to the methyl formate gas in the Monitor-top fridge, which transforms it into a liquid.

Refrigerant vapour
The cool refrigerant liquid is passed through a valve and expands back to a partial gas state, taking heat from the air in the cabinet in the process.

© Getty

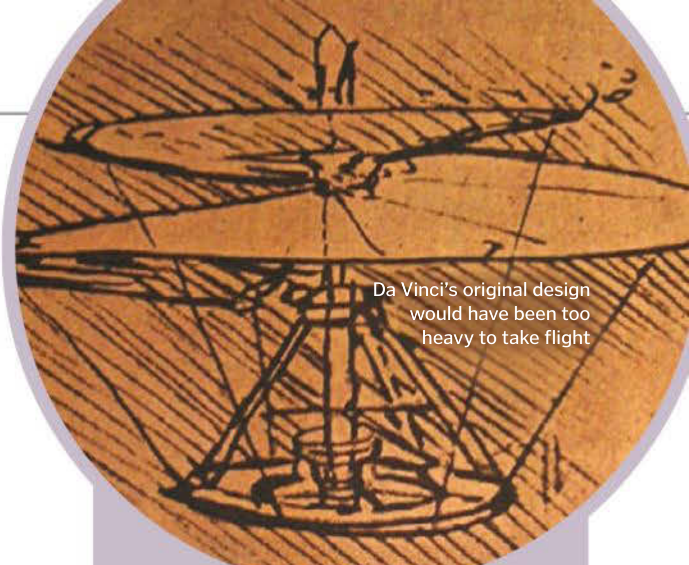
How Leonardo da Vinci tried to fly

Discover the secrets behind the legendary inventor's incredible flying machine

Few individuals truly fit the much-overused sobriquet of 'man ahead of his time', but Leonardo da Vinci is one of the select band who undoubtedly fits into this category. His mind seemed to be of another time entirely, devising all sorts of inventions and machines that would either pre-empt or form the basis for modern-day equivalents. The item that perhaps best of all encapsulates his capacity to work beyond the constraints of his time, however, is his visionary ornithopter flying machine.

Having spent much time watching and studying the flight of birds, he observed the different ways they flapped their wings while taking off and in mid-flight, and sought to mimic them in the construction of his ornithopter. Sharing similarities with the paragliders of today, it required a solo pilot to manually operate a system of pullies, levers and pedals with his hands and feet in order to simulate flight. A hand crank increased the production of energy and the wings were designed to flap – much like those of a bird.

However, while it looked impressive on the page, da Vinci's ornithopter was never physically realised in his day. While it may well have worked while in flight, the task of actually taking off proved to be an insurmountable obstacle, as there wasn't a known way of producing enough power to actually get it off the ground.



Da Vinci's original design would have been too heavy to take flight

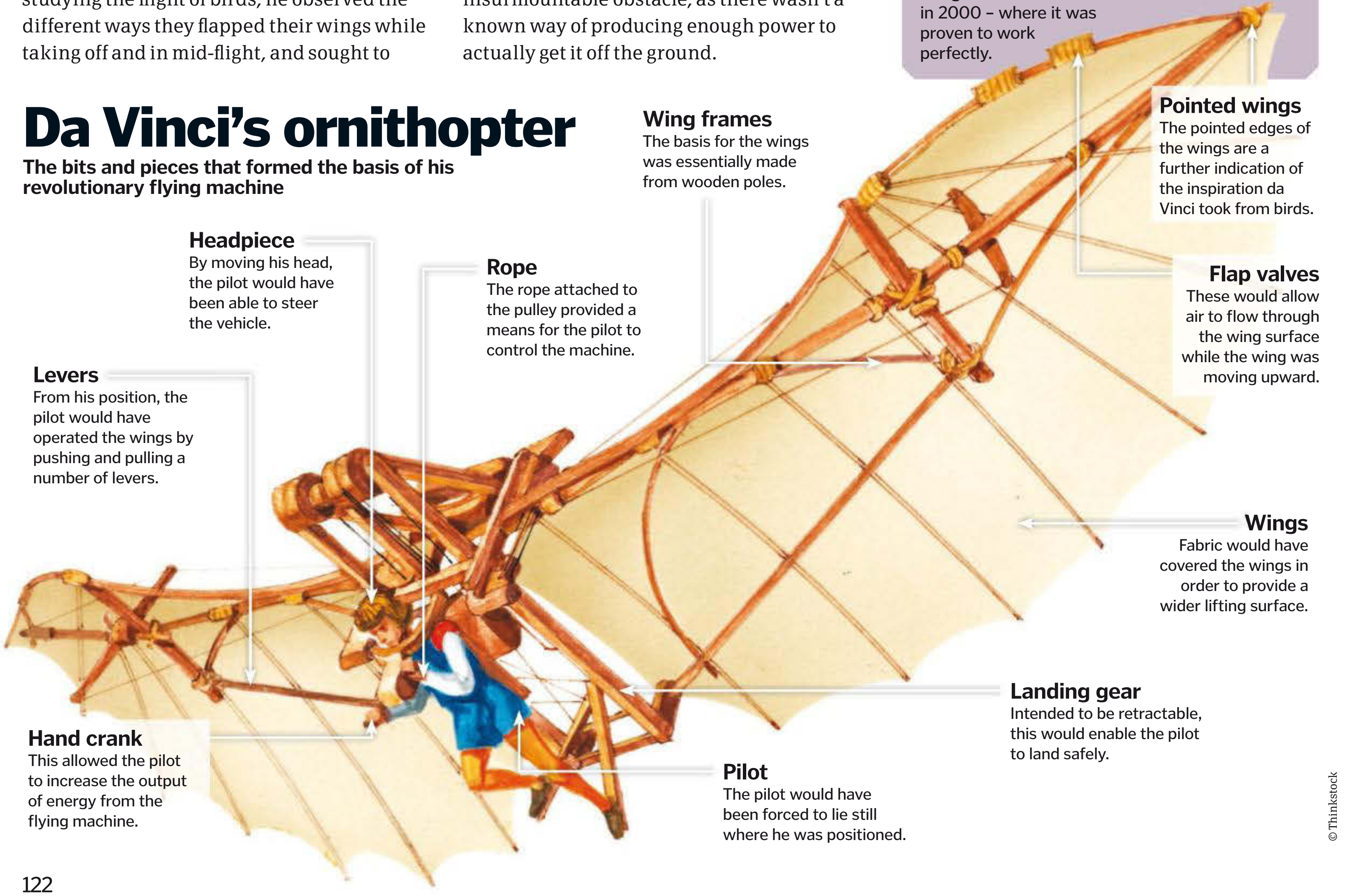
Da Vinci's other flying machines

Da Vinci didn't limit his pursuit of flight to just his ornithopter. Predating its invention by over 400 years, one of his designs reveals something akin to a modern-day helicopter. Also known as an aerial screw, its blades revolved like a corkscrew, compressing air in order to gain flight – a principle shared by its eventual successors. Although the theory was sound, modern-day scientists believe that it would have been too heavy to achieve flight, and as such remained strictly in the drawing book.

He is also credited with devising early designs for what would become what we know as the parachute. Despite its triangular shape and wooden frame causing many to doubt its effectiveness, it a prototype based on the same design was constructed and tested in 2000 – where it was proven to work perfectly.

Da Vinci's ornithopter

The bits and pieces that formed the basis of his revolutionary flying machine



Wing frames
The basis for the wings was essentially made from wooden poles.

Pointed wings
The pointed edges of the wings are a further indication of the inspiration da Vinci took from birds.

Headpiece
By moving his head, the pilot would have been able to steer the vehicle.

Rope
The rope attached to the pulley provided a means for the pilot to control the machine.

Flap valves
These would allow air to flow through the wing surface while the wing was moving upward.

Levers
From his position, the pilot would have operated the wings by pushing and pulling a number of levers.

Wings
Fabric would have covered the wings in order to provide a wider lifting surface.

Landing gear
Intended to be retractable, this would enable the pilot to land safely.

Hand crank
This allowed the pilot to increase the output of energy from the flying machine.

Pilot
The pilot would have been forced to lie still where he was positioned.

© Thinkstock

DID YOU KNOW? *The 'His Master's Voice' image of Nipper the dog listening to a gramophone originally featured a phonograph*

How the gramophone worked

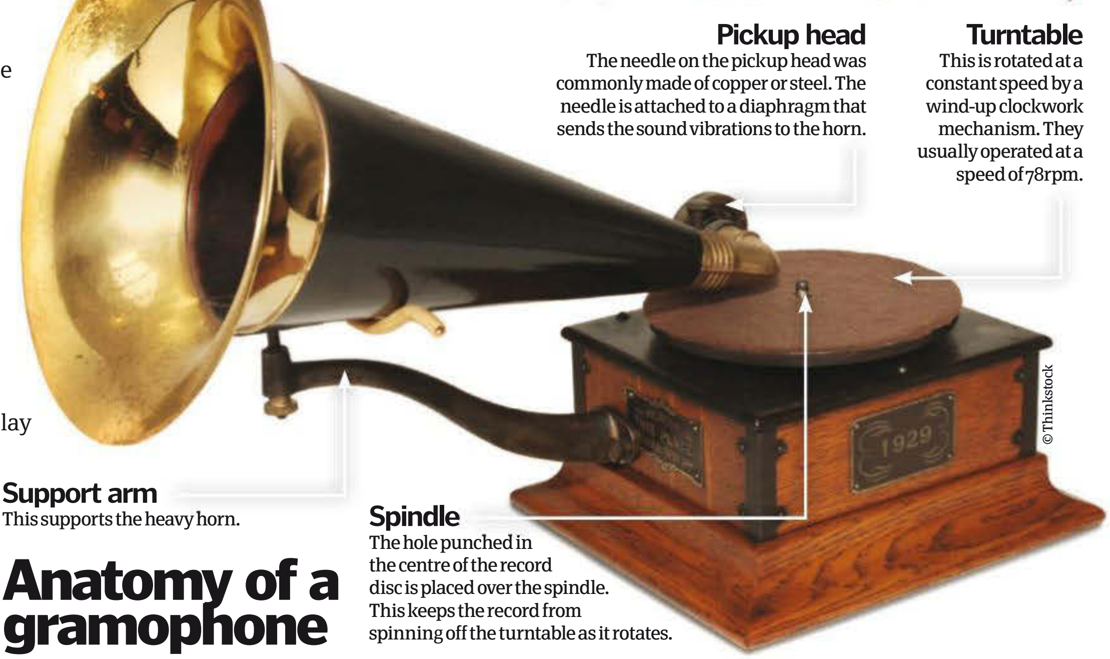
The invention that brought sound to the home explained

In the 19th Century, there was fierce competition in Europe and the USA to create machines that could record and playback music and sounds. As early as 1857, the phonautograph, created by Édouard-Léon Scott de Martinville, used a diaphragm attached to a bristle that responded to sound vibrations. These vibrations were traced onto a sheet of paper coated in soot, which was wrapped around a rotating cylinder. This, however, could unfortunately not play back the recording.

In the year 1877, Thomas Edison's phonograph followed quite a similar principle to the phonautograph, but used tinfoil wrapped over a grooved cylinder. The vibrations of a needle attached to a diaphragm and horn made indentations in the foil, and to play it back the needle retraced the indentations in the foil. Wax cylinders enabled such recordings to be played back more than just once.

Ten years later, Emil Berliner introduced the gramophone that used discs with a spiral groove, rather than a cylinder to record and play back the sound. It still used a horn and needle, but unlike cylinders, the master recording could be easily copied onto a mould and mass-produced. The gramophone came to dominate the market in the Twenties, superseded by the electronic record player.

Sled dog and gramophone, Terra Nova Expedition



Anatomy of a gramophone

Horn Amplifies and projects the sound from the needle (stylus). A ball or material was put into the horn to reduce the sound from the horn.

Pickup head The needle on the pickup head was commonly made of copper or steel. The needle is attached to a diaphragm that sends the sound vibrations to the horn.

Turntable This is rotated at a constant speed by a wind-up clockwork mechanism. They usually operated at a speed of 78rpm.

Support arm This supports the heavy horn.

Spindle The hole punched in the centre of the record disc is placed over the spindle. This keeps the record from spinning off the turntable as it rotates.

© Thinkstock

The bow drill

An ancient device that uses friction to light fires

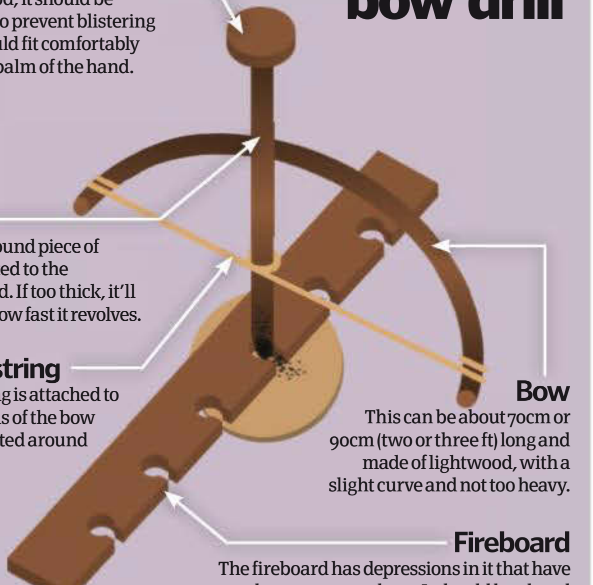
The bow drill works by pressing down on the handhold at the top of the drill with one hand, while moving the bow horizontally backwards and forwards with the other hand. This makes the drill revolve fast enough to create friction and subsequently heat on the fireboard.

The hot sawdust produced by this action falls down the notch at the side of the fireboard and ignites dry leaves or other tinder material. Once this is lit, the burning tinder can be removed and used elsewhere.

The Ancient Egyptians used the bow drill as long ago as 3000BC, with the bow string wrapped several times around the drill, to produce holes in wood and stone rather than to light fires. Carpenters are even depicted using this device on the fifth dynasty tomb of an important official called Ti, at Saqqara.

© Science Photo Library

Parts of the bow drill



Handhold Made of stone, bone or hardwood, it should be smooth to prevent blistering and should fit comfortably into the palm of the hand.

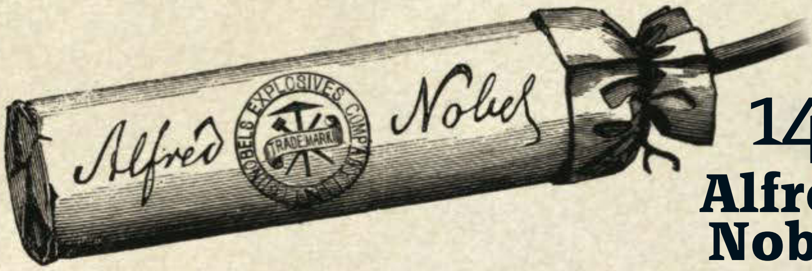
Drill A thin, round piece of wood fitted to the handhold. If too thick, it'll reduce how fast it revolves.

Bow string The string is attached to both ends of the bow and twisted around the drill.

Bow This can be about 70cm or 90cm (two or three ft) long and made of lightwood, with a slight curve and not too heavy.

Fireboard The fireboard has depressions in it that have notches cut next to them. It should be placed on a dry base to protect it from damp ground.

INFLUENTIAL FIGURES



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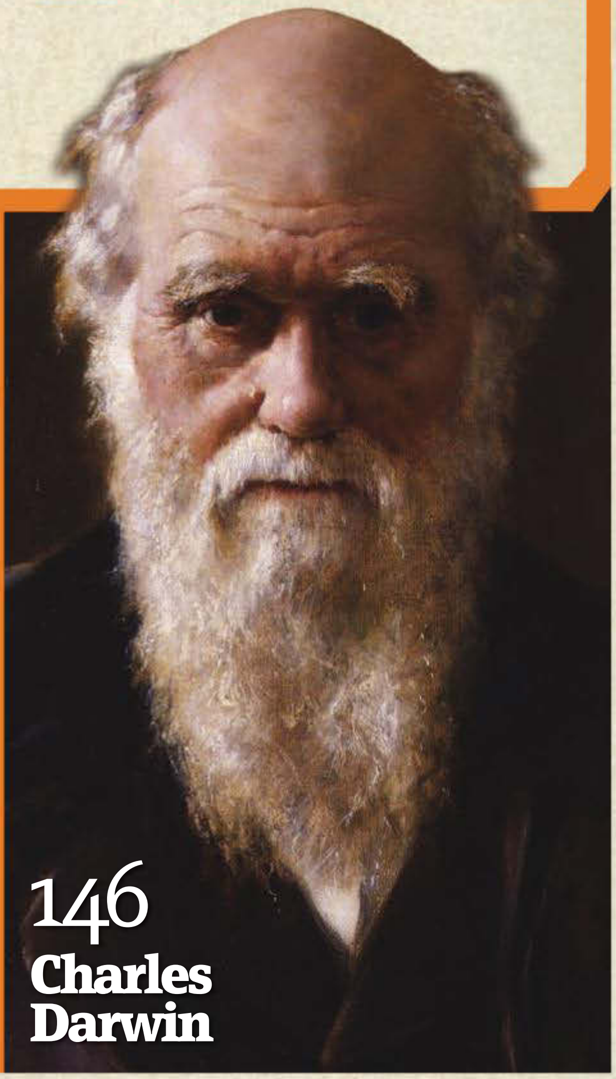
The father of evolutionary biology, Darwin is the most famous naturalist of the Victorian era, if not all time



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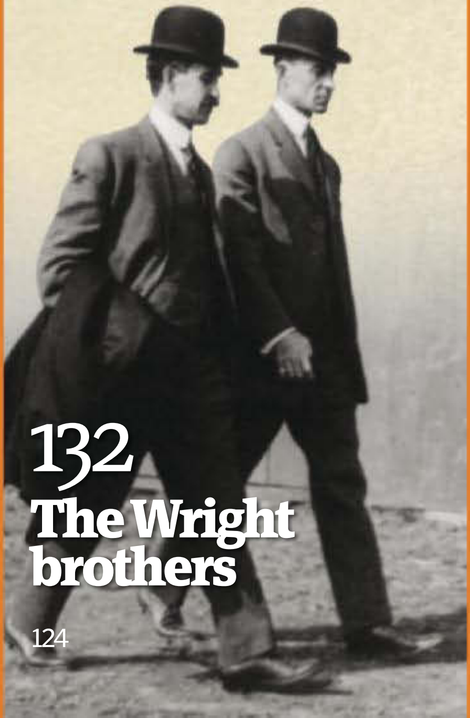
Charles Darwin



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The Wright brothers

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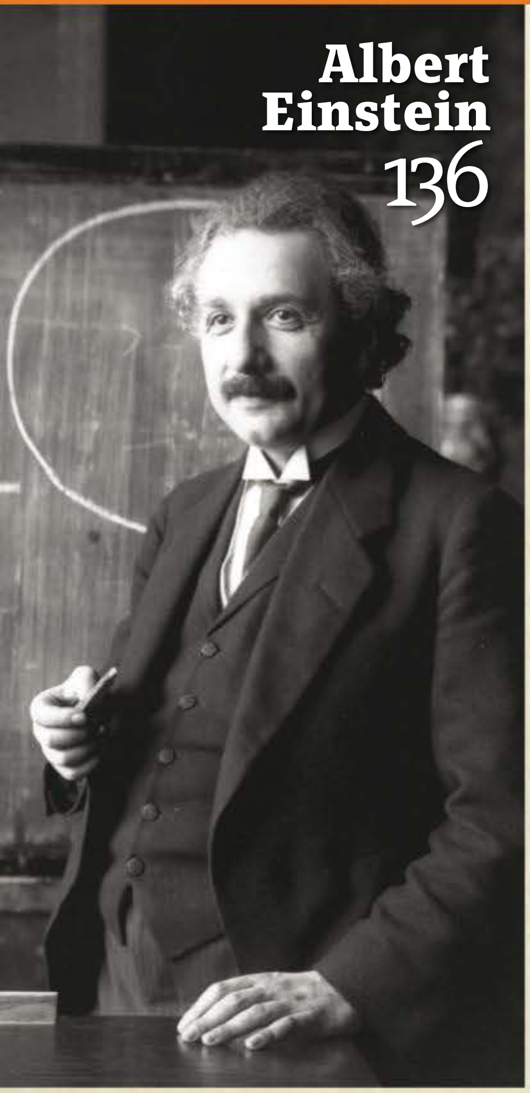

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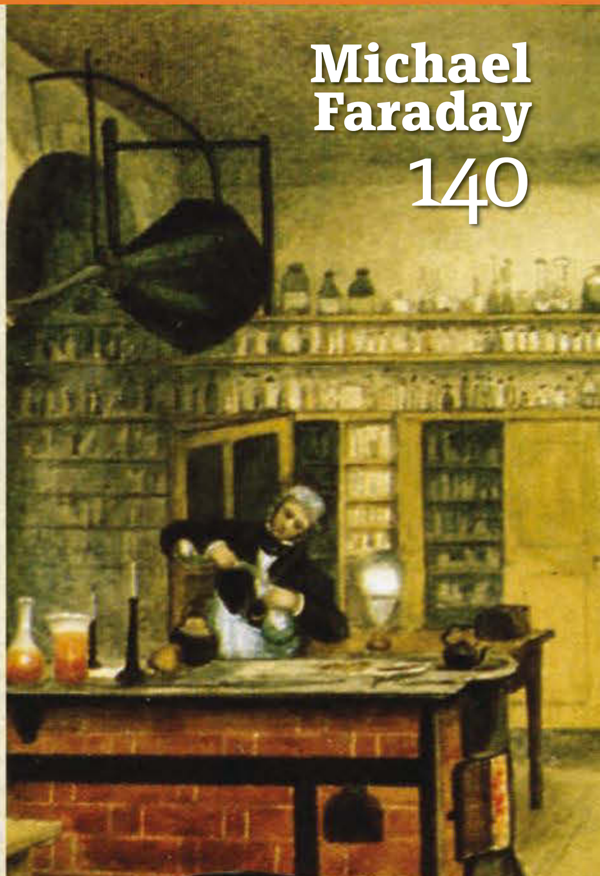

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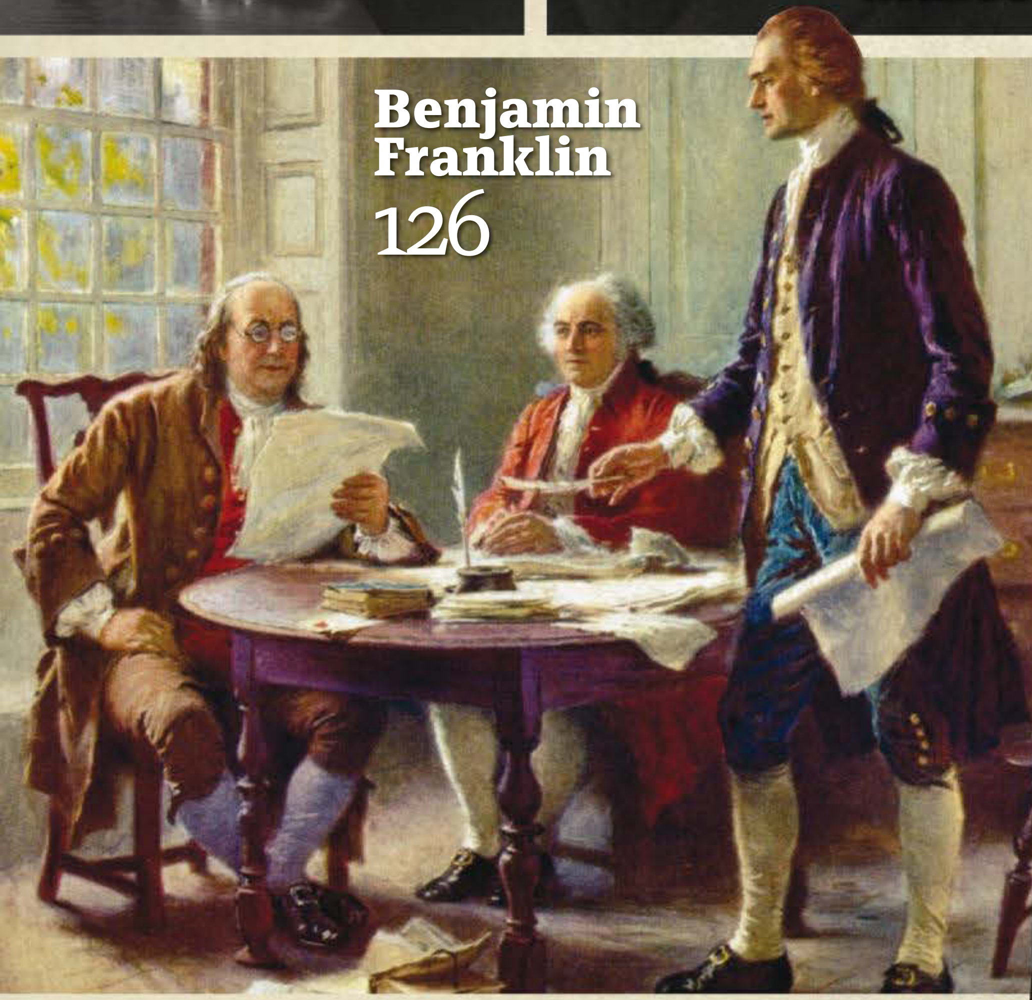

Benjamin Franklin
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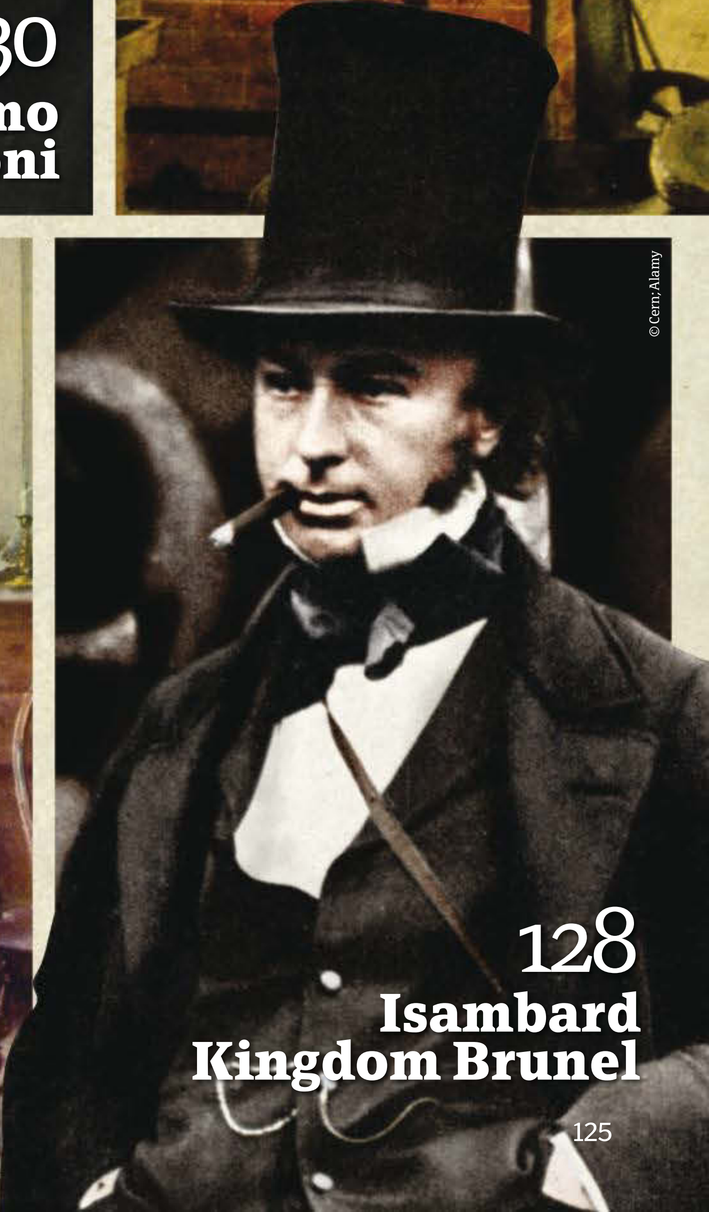

128
Isambard Kingdom Brunel

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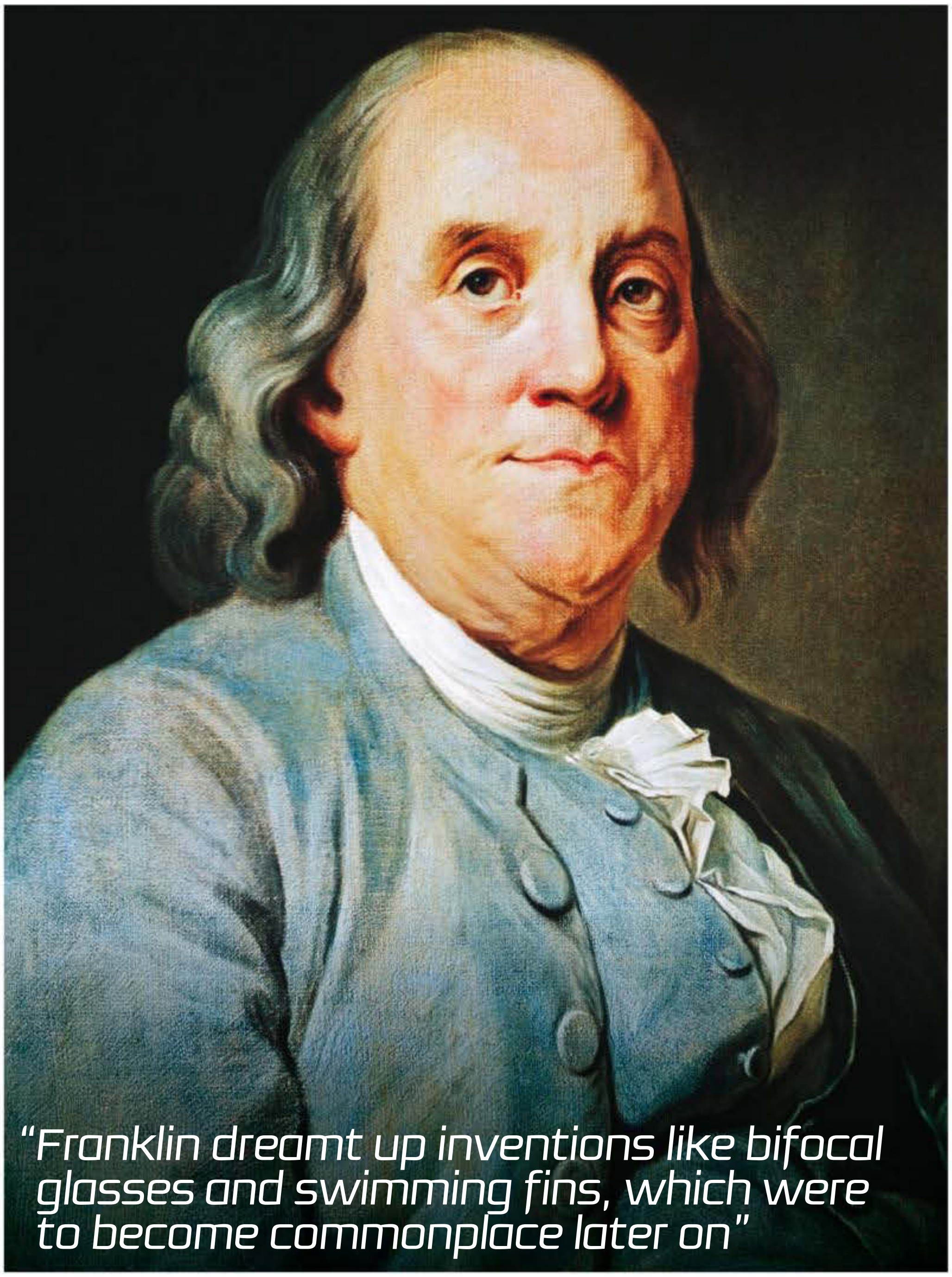
Benjamin Franklin

How the man on the $100 bill revolutionised technology just as much as American politics



"Franklin dreamt up inventions like bifocal glasses and swimming fins, which were to become commonplace later on"

Benjamin Franklin, one of the greatest minds of all time, had his first big break while pretending to be a woman. At 12 years old, he began an apprenticeship at his brother James' printing shop, which published the first independent newspaper in the colonies. But despite Benjamin's determination and hard work, James refused to print any of his articles. Instead, the young Franklin began writing under the pseudonym 'Mrs Silence Dogood', regularly sending letters to the paper for publication. 'Her' witty and insightful commentary became the talk of the town, but James was outraged when he discovered that the true author was in fact his younger brother. Benjamin Franklin abandoned his apprenticeship and moved to Philadelphia, where he set up his own printing business and purchased *The Pennsylvania Gazette*.

The 1730s saw his prominence and success grow, especially with his publication of the *Poor Richard's Almanack*. Franklin bought properties and businesses, organised a volunteer fire department, established a lending library and was elected grand master of the Pennsylvania Masons, clerk of the state assembly and postmaster of Philadelphia. He also began to expand into entrepreneurship, and in 1741 he invented the Franklin stove – a heat-efficient fireplace that aimed to produce less smoke and more heat than the ordinary open fireplaces on the market. While the stove failed to take off, in 1749 he retired from business to concentrate more on his inventions, dreaming up things like bifocal glasses and swimming fins that were to become commonplace. Never one to rest on his laurels, Franklin then turned his attention to the study of electricity, and in 1752 conducted the famous kite-and-key experiment, which proved that lightning was made up of static electricity. He also developed the single fluid theory, which proposed that electricity was a 'common element' rather than two opposing forces.

The 1750s saw Franklin become more involved in politics. In 1757, he travelled to England to represent Pennsylvania in its fight with the descendants of the Penn family over who should represent the colony. On his return almost 20 years later, he fought fiercely for American sovereignty, and was one of the five

A life's work

We travel through the various key events that defined the famous polymath's career

1706
Franklin is born in Boston on 17 January to Josiah Franklin and his wife Abiah.

1718
At the age of 12, Franklin begins an apprenticeship at his brother's new printing business.

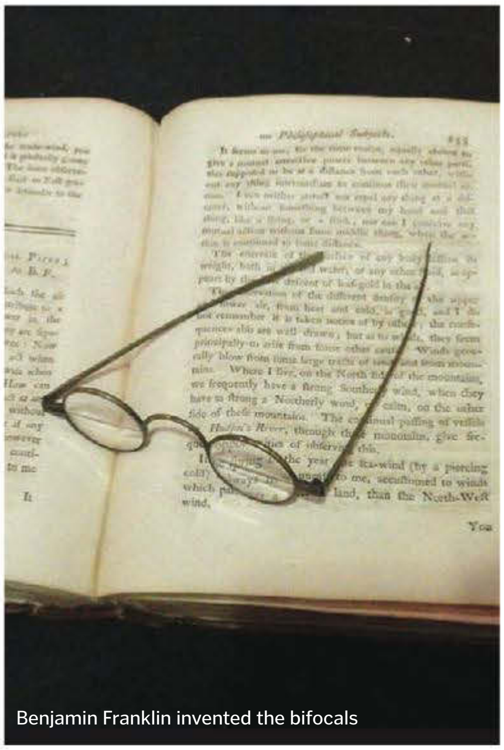
1723
After publishing work under a false name, Franklin runs away to Philadelphia.

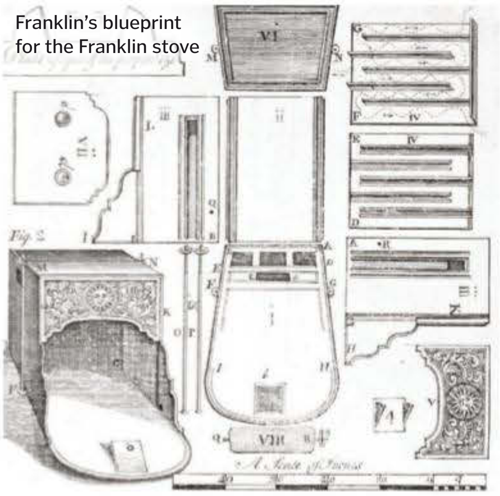
1728
Franklin establishes his own printing company and purchases *The Pennsylvania Gazette* the following year.

1732
Franklin publishes the first edition of the *Poor Richard's Almanack*, which quickly becomes very popular.

Almanack
1739

DID YOU KNOW? *Franklin remained a printer to his end, and wherever he lived he made sure he had a printing press to hand*


Benjamin Franklin invented the bifocals

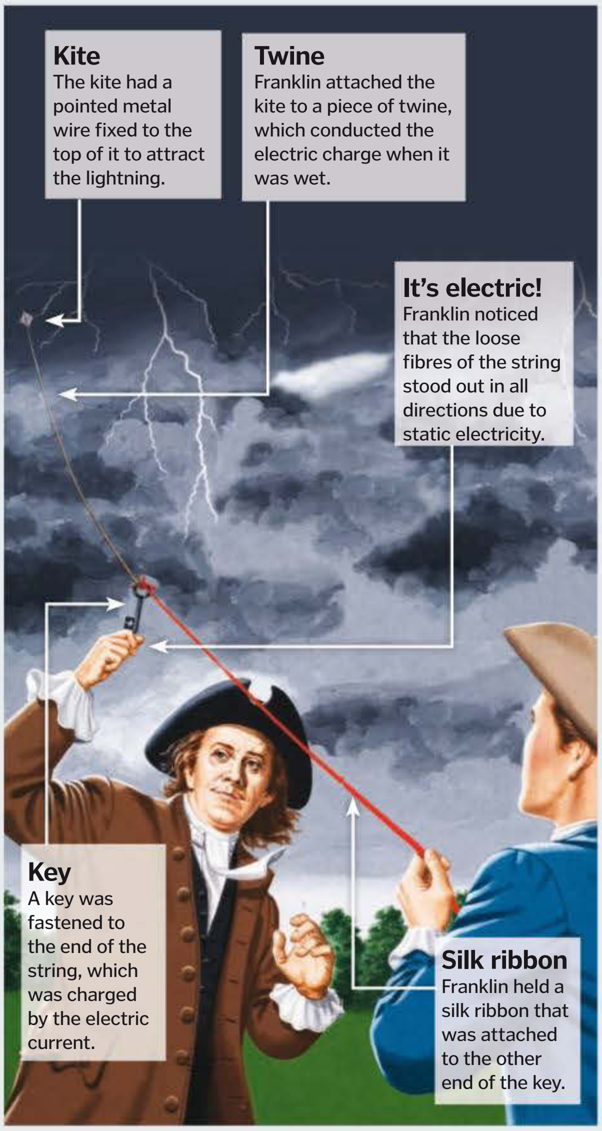

Franklin's blueprint for the Franklin stove

people who drafted the Declaration of Independence in 1776. Later that year he went to France as a diplomat for the United States where he became a much-loved figure, and it was largely because of him that the government of France signed a Treaty of Alliance with the USA in 1778.

When Franklin died in 1790, he was dubbed 'the harmonious human multitude.' The legacy of his inventions and political work lives on to this day.

The big idea

Before Franklin began his experiments in science, the popular belief was that electricity consisted of two opposing forces. Franklin proved that in fact it was a single element, imagining it to be like an invisible fluid. If a body had an excess of this fluid, it was positively charged. If it had a deficiency, it was negatively charged. He theorised that the body with more fluid flowed to the body with less fluid, or rather that electric charges flowed from positive to negative. However, it has since been discovered that electricity is actually the flow of electrons, which means it flows from negative to positive.



Kite
The kite had a pointed metal wire fixed to the top of it to attract the lightning.

Twine
Franklin attached the kite to a piece of twine, which conducted the electric charge when it was wet.

It's electric!
Franklin noticed that the loose fibres of the string stood out in all directions due to static electricity.

Key
A key was fastened to the end of the string, which was charged by the electric current.

Silk ribbon
Franklin held a silk ribbon that was attached to the other end of the key.

Five Franklin inventions

1 Bifocals
Franklin suffered from poor eyesight, but came up with the brilliant idea of creating glasses with a separate upper and lower half; the upper for distance and the lower for reading.

2 Lightning rod
After studying the behaviour of electricity, Franklin designed a metal rod that could be attached to the tops of buildings and connected to the ground through a wire to discharge lightning.

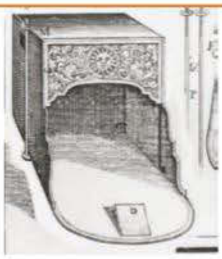
3 Glass armonica
A popular form of entertainment in the 18th century was playing music using wine glasses filled with water. Franklin invented a mechanised version consisting of 37 glass bowls.

4 Franklin stove
This metal-lined fireplace stood in the centre of the room, radiating heat in all directions. It provided more heat, used less wood and produced less smoke than open fireplaces.

5 'Long arm'
Franklin loved reading and established a number of libraries. His idea for a wooden pole with a grasping claw at the end helped visitors to reach books on the top shelves.

> *"He fought for American sovereignty, and was one of the five people who drafted the Declaration of Independence in 1776."*

1741
The efficient Franklin stove is invented but fails to take off as a product.



1752
Through his kite experiment, Franklin proves lightning is an electrical phenomenon.

1776
Franklin signs the Declaration of Independence, signalling the United States' independence from the British Empire.

1783
The Treaty of Paris is signed, ending the American Revolutionary War.

1790
Franklin dies on 17 April aged 84. Over 20,000 mourners attend his funeral.

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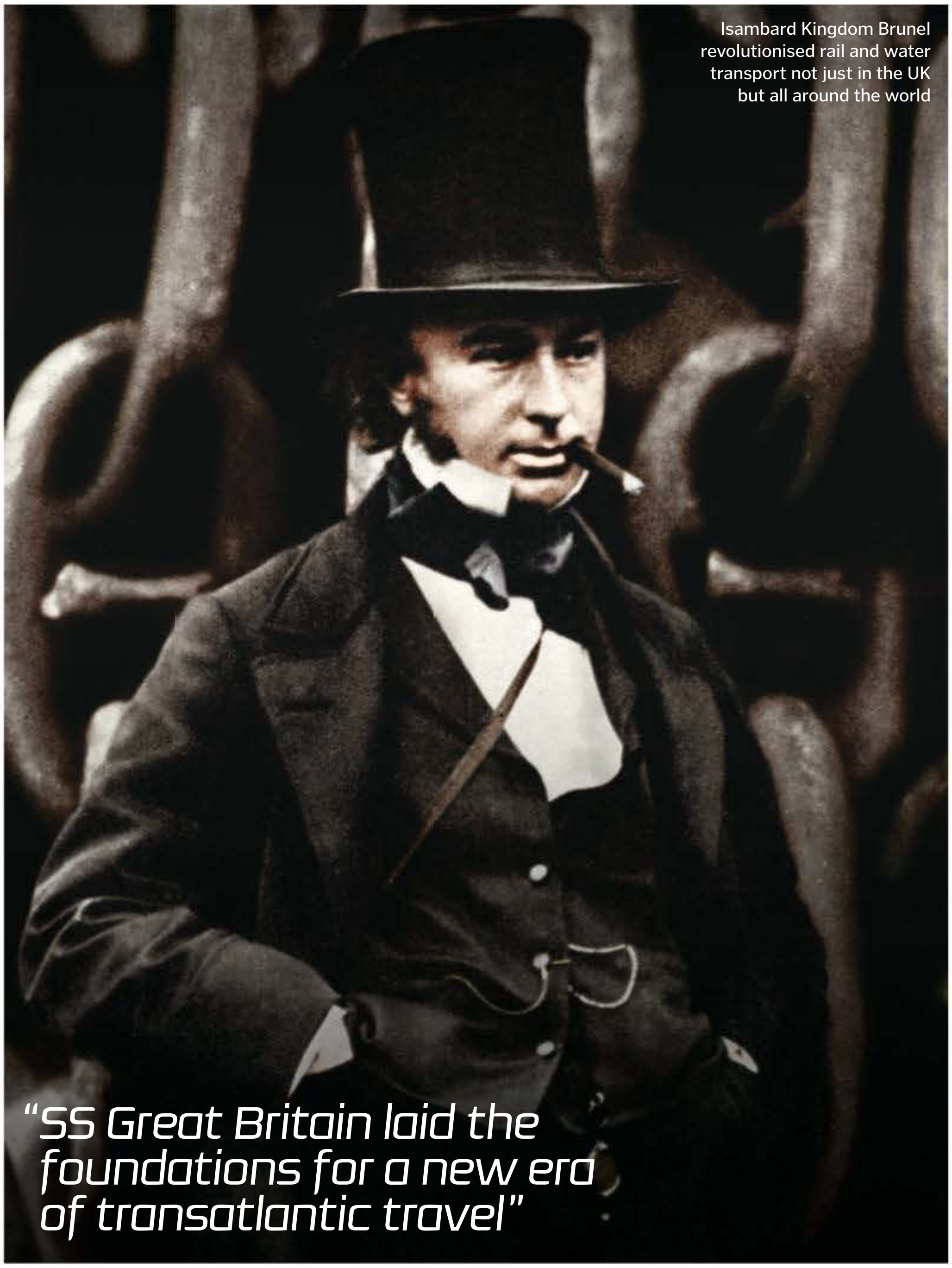
Isambard Kingdom Brunel

Though not always successful, Brunel's designs revolutionised transport, and he is now remembered as one of the greatest engineers of all time



Isambard Kingdom Brunel revolutionised rail and water transport not just in the UK but all around the world

> "SS Great Britain laid the foundations for a new era of transatlantic travel"

While an era of progress, the Industrial Revolution was also a time of trial and error. Those leading the way in technological advances attempted to make huge leaps forward, often resulting in failure, but sometimes incredible success. One of the greatest of the innovators of this time was Isambard Kingdom Brunel, born at the start of the 19th century. His father, Marc, was a French civil engineer, and encouraged his son to learn arithmetic, scale drawing and geometry. At 16, he became a watchmaker's apprentice.

In 1824 Marc was appointed chief engineer of a project to construct a tunnel under the River Thames. He hired his son as an assistant engineer, who later became resident engineer. The project was fraught with disaster, witnessing several incidents of flooding, as well as financial difficulties. At one point the operation was halted for several years and the tunnel bricked up. It was eventually opened in 1843 and is still in use today as part of the London Overground network.

The project transformed the young Brunel into a full-fledged engineer. In 1830 he entered a competition to design a bridge that would span across the River Avon in Bristol, and although rejected initially, he eventually persuaded the panel to appoint him as project engineer. Work on the Clifton Suspension Bridge commenced in June 1831, but just four months later the Queen Square riots drove investors away. Once again a project ground to a halt.

In 1833 Brunel was made chief engineer of the Great Western Railway, which would run from London to Bristol. It was then that he developed one of the most controversial ideas of his career – to use a 2.1-metre (seven-foot) gauge (distance between the tracks) rather than the standard 1.4-metre (4.6-foot) gauge. He believed that this would allow the trains to run at much higher speeds, as well as provide a more stable and comfortable journey without as much rocking

A life's work

Brunel made his mark on history – but what were the defining moments in this innovator's career?

1806

Isambard Kingdom Brunel is born in Portsmouth, UK, to French civil engineer Marc Isambard Brunel and Sophia Kingdom.

1827

Brunel is appointed resident engineer of the Thames Tunnel project in London, taking over from his father.

1830

He enters a competition to design a bridge to span the River Avon and is awarded first place.

1831

Work on the Clifton Suspension Bridge begins but financial difficulties bring the project to a halt.

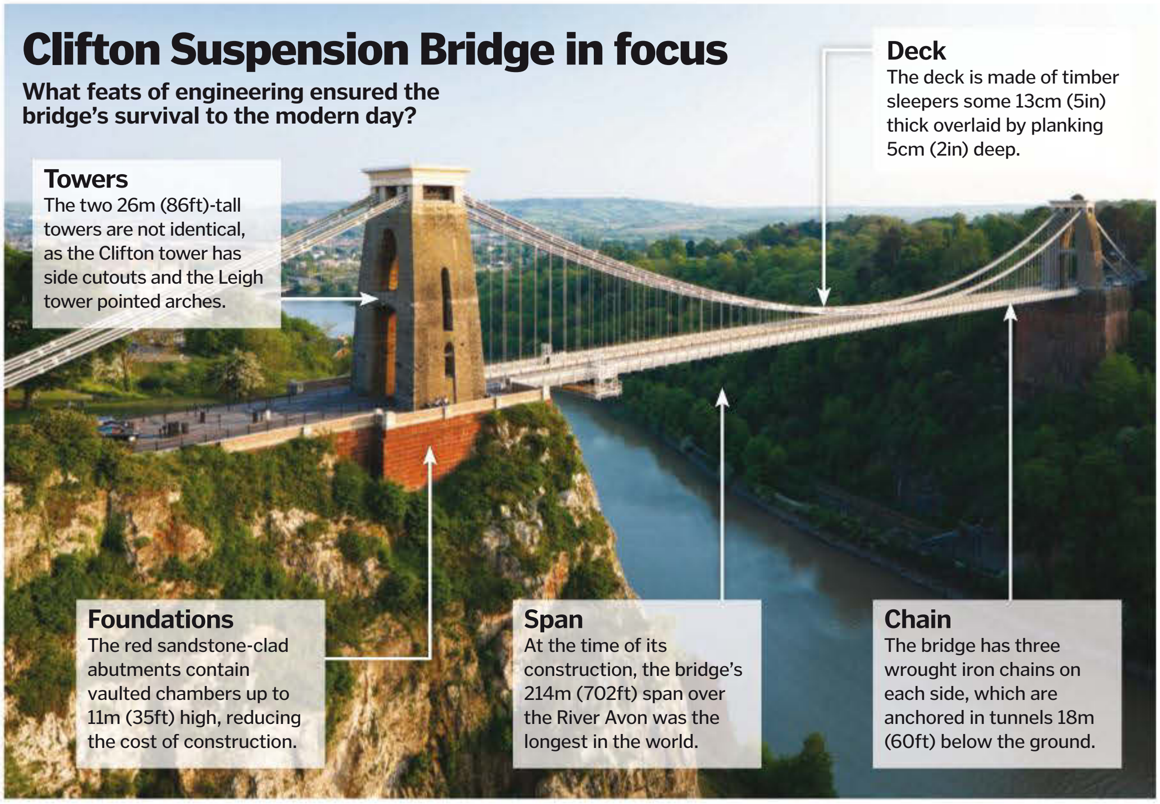
1833

Brunel becomes chief engineer of the Great Western Railway, developing his idea for a wider track.

DID YOU KNOW? *Brunel University in Uxbridge, London, established in 1966, is named after Brunel*

Clifton Suspension Bridge in focus

What feats of engineering ensured the bridge's survival to the modern day?



Towers
The two 26m (86ft)-tall towers are not identical, as the Clifton tower has side cutouts and the Leigh tower pointed arches.

Deck
The deck is made of timber sleepers some 13cm (5in) thick overlaid by planking 5cm (2in) deep.

Foundations
The red sandstone-clad abutments contain vaulted chambers up to 11m (35ft) high, reducing the cost of construction.

Span
At the time of its construction, the bridge's 214m (702ft) span over the River Avon was the longest in the world.

Chain
The bridge has three wrought iron chains on each side, which are anchored in tunnels 18m (60ft) below the ground.

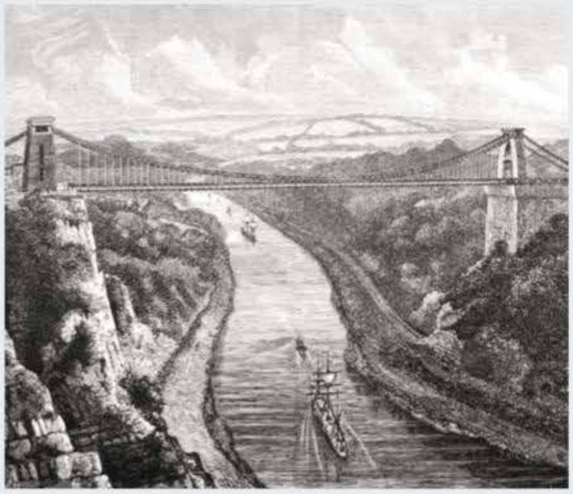
back and forth. For the rest of his life the efficiency of this design was heavily contested.

But none could contest the efficiency of his Great Western Steamship, which transported passengers from Bristol to New York. It was thought a steamship would not be able to carry enough fuel for the trip and have room for cargo. However, it completed its maiden voyage in 15 days, with a third of its coal remaining. Brunel was also a fierce proponent of propeller-driven ships and incorporated a propeller on his second ship, SS Great Britain. Considered the first modern ocean-going ship, it was made of metal, powered by an engine rather than wind, and driven by a propeller rather than a paddle wheel. Indeed, this vessel laid the foundations for a new era of transatlantic travel.

Brunel's personal life was a series of ups and downs too. Many say the stress of the Great Western Railway led to his early death in 1859. Soon after it was decided all railways in the country should revert to using the standard gauge. However, funds were also raised to complete the Clifton Bridge, which was opened five years after Brunel's death and is still in use.

The big idea

The Clifton Suspension Bridge in Bristol spans 214m (702ft) between two 26.2m (86ft) towers, which then was the longest bridge span in the world. In its design of chains and rods, Brunel had made a near-perfect calculation of the minimal weight required to provide maximum strength. The abutments contain a honeycomb of chambers and tunnels, some of which are 11m (36ft) high, which reduced the cost of construction without compromising strength.



Brunel trivia

1 French connection

During his teenage years, Brunel attended school in France, but surprisingly his application to the renowned French engineering school École Polytechnique was unsuccessful, owing to the fact that he was a 'foreigner'.

2 River party

In 1827, after several incidents of flooding, Brunel held a lavish banquet inside the Thames Tunnel to help convince people that it was perfectly safe.

3 Beating the competition

Brunel's submission to the Clifton Bridge competition was initially rejected by the judge, Thomas Telford, who instead put forward his own design.

4 Flip of a coin

In 1843, while performing a magic trick for his children, a coin became lodged in Brunel's windpipe. In order to remove it, he was strapped to a board and turned upside down.

5 Commissioned by the lady with the lamp

In 1855 Brunel responded to a request from Florence Nightingale, known as nursing icon 'the lady with the lamp', to design a new hospital that would replace the unsanitary British Army Hospital in Scutari, Turkey, which he did successfully.

1838
The Great Western Steamship sails from Bristol to New York in just 15 days.

1843
The Thames Tunnel is opened to the public and the propeller-driven SS Great Britain is launched.

1852
Brunel's design for Paddington Station is constructed.

1859
Brunel dies on 15 September, ten days after suffering a stroke.

1864
The Clifton Suspension Bridge is finally completed as a tribute to Brunel by the Institute of Civil Engineers.

© Alamy; National Maritime Museum

Guglielmo Marconi

Sometimes called the father of radio, this resourceful inventor's practical telegraphy system led to the widespread use of wireless communications

Marconi developed his radio equipment in the attic of his parents' home in Italy, with the help of his butler, Mignani

> *"The Marconi room aboard the RMS Titanic and its two Marconi wireless operators transmitted the most famous radio signals of all time"*

Guglielmo Giovanni Maria Marconi was a famous and widely respected Italian inventor who pioneered the development of wireless communication and long-distance radio transmission.

Often credited as the inventor of radio, Marconi was actually an astute businessman who combined, and built upon, the work of other scientists to develop a commercially viable method of long-distance communication.

His interest in electricity and physics began at an early age, and he was inspired by the work of scientists like James Clerk Maxwell, Heinrich Hertz and Nikola Tesla, among others.

In 1894, Marconi read the work of German physicist Hertz, who had developed equipment to send and detect electromagnetic waves over short distances. Marconi saw the potential for transmitting information using radio waves and set about developing a longer-range system to replace wire-based telegraphy.

Marconi began his experiments at his father's estate and with the help of his butler, Mignani, built equipment in the attic. Soon he could transmit radio waves over short distances, so he moved his experiments outdoors to develop the technology further. He found that increasing the length of the antennas – and arranging them vertically – increased the range of transmission so much that he was able to send and receive signals over distances of around 2.4 kilometres (1.5 miles).

It was at this point that Marconi began to see the potential commercial applications of his experiments. Italy already had a well-established telegraph system though, with networks of wires extending across the country, and his applications for funding were dismissed. Undeterred, Marconi travelled to the UK. Britain had a powerful Royal Navy and was the world's greatest trading empire, and his thinking was that they might have use for his work in maritime communication.

A life's work

Tune in to some of the major events from the lifetime of this astute Italian radio pioneer

1874
Guglielmo Marconi is born in Bologna, Italy, to landowner Giuseppe Marconi and his Scots-Irish wife Annie Jameson.

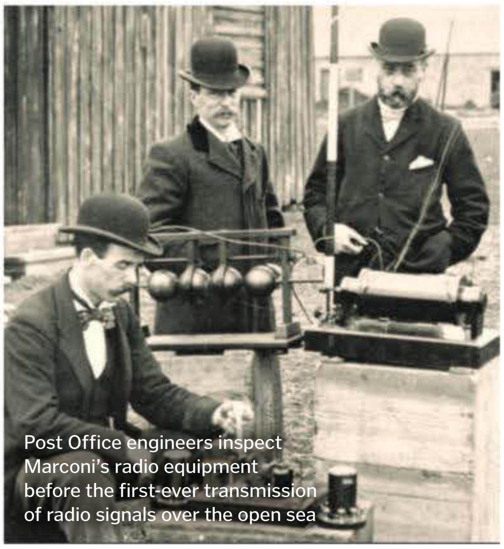
1894
Begins to develop a method of transmitting telegraph messages without wires, using radio waves.

1896
Travels to London, where he gains the support of engineer-in-chief of the Post Office, William Preece.

1899
Sets up the first wireless link between Britain and France from Wimereux, France, to a lighthouse in Dover, England.

1900
Takes out his No 7777 'Improvements in Apparatus for Wireless Telegraphy' patent to protect his technological developments.

DID YOU KNOW? *Marconi's wireless experiments disproved the dominant belief that the Earth's curvature affected transmission*



Post Office engineers inspect Marconi's radio equipment before the first-ever transmission of radio signals over the open sea

Marconi gained the support of the engineer-in-chief of the British Post Office and, with his help, demonstrated his technology to the British government. During his first few years in England he gradually improved the distance of radio transmission – first on land and then over sea. His work excited the international community and stations were set up in France for the first radio crossing of the Channel.

As his technology continued to evolve, 'Marconi rooms' were installed in ships, containing a suite of wireless telegraphy equipment which enabled communication with land as well as other vessels. The Marconi room aboard the RMS Titanic and its two Marconi wireless operators transmitted perhaps the most famous radio signals of all time: 'CQD CQD SOS Titanic position 41.44 N 50.24 W. Require immediate assistance. Come at once. We struck an iceberg. Sinking'.

Marconi died in Rome in 1937 at the age of 63. He was given a state funeral and – as a tribute to his massive contribution to wireless communication – every radio station in the world fell silent for two minutes.

> *"Marconi saw the potential for transmitting information using radio waves"*

The big idea

Marconi combined and modified the inventions of other scientists to develop equipment that could transmit radio waves over great distances. He used a spark-gap transmitter to generate radio frequency electromagnetic waves and a coherer receiver to detect them. A telegraph key enabled him to send radio waves in bursts, generating Morse code. Marconi discovered that the maximum distance of radio wave transmission varied according to the square of the height of the transmitting antenna – tall, vertical antennas were key.

Five facts: Guglielmo Marconi

1 Royal connections

Marconi installed radio equipment on Queen Victoria's royal yacht so that she could communicate with the Prince of Wales (Edward VII) while travelling.

2 Educated but unqualified

Marconi had no formal scientific qualifications, but had a keen interest in physics. At the request of his mother, he was mentored by physicist Professor Augusto Righi, who introduced him to radio waves.

3 Are you ready?

The first radio transmission across the open sea was sent over the Bristol Channel and travelled a distance of just 6.4 kilometres (four miles). It read 'Are you ready'.

4 High-speed Morse

To be employed as a wireless operator by Marconi's Wireless Telegraph Company you had to be able to send and receive Morse code at a speed of 25 words per minute.

5 Lucky escape

Marconi was offered free passage on the famous doomed ship RMS Titanic, but decided to travel to America three days earlier on the RMS Lusitania because he had paperwork to do.

1901

Successfully transmits the letter 'S' in Morse code 3,380km (2,100mi) across the Atlantic Ocean to Newfoundland.

1909

Receives the Nobel Prize in Physics – along with Karl Ferdinand Braun – for their contribution to wireless telegraphy.

1912

Marconi radio is used to save victims of the Titanic, and passes distress signals from the sinking ship to the RMS Carpathia.

1914

Joins the Italian war effort during World War I, where he takes charge of the military's radio service.

1937

Marconi dies aged 63. He receives a state funeral in Italy and all radio stations hold a two-minute silence in his honour.

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The Wright brothers

These siblings played a pivotal role in the evolution of powered flight and radically altered the path of aviation history

Wilbur (right) and Orville attend the Belmont Park Aviation Meet, NY, in 1910

Wilbur and Orville Wright are two of history's most famous aviation pioneers who, through a series of experiments in the late-19th and early-20th centuries, created the first controllable, powered, heavier-than-air aircraft. Named the Wright Flyer, the plane was the culmination of over a decade's worth of research and trials that saw the brothers progress from custom-built kites, through to gliders and finally on to engine-powered aeroplanes. Together these talented siblings are generally credited with launching the age of powered flight.

Wilbur and Orville Wright were the sons of Milton Wright, an ordained minister of the Church of the United Brethren in Christ, and Susan Catherine Koerner Wright. The family lived in various locations including Richmond, IN; Cedar Rapids, IA; and Dayton, OH – the latter for the majority of the brothers' lives. Orville later explained that his father had encouraged both of them from an early age "to pursue intellectual interests and to investigate whatever aroused curiosity."

This encouragement led Orville and Wilbur into a diverse range of interests and expertise including printing, bicycles – which the pair sold and repaired for several years – and the construction of various machines from wood and metal. Both engineers and inventors, the brothers became well known for their academic and practical application of modern engineering, with Wilbur especially spending much time in his father's and public libraries.

One of their heroes was German gliding pioneer Otto Lilienthal, who up until his death in 1896 had built and flown a series of aircraft to varying degrees of success. His death, however – which was the result of a glider crash – oddly spurred the brothers' interest in flight, with them writing to the Smithsonian Institution for suggestions on other aeronautical manuscripts. One of the museum's recommendations was the engineer Octave Chanute, a leading authority on aviation and civil engineering at the time.

With Chanute's help the brothers began conducting a number of aeronautical experiments. Crucial to their approach was the focus on control of the aircraft, advancing previous designs that could only fly in a straight line by introducing a helical twist across the wings in either direction. The brothers tested this configuration in 1899 and, after discovering that it allowed the acute control of a kite, began working on a full-scale model: the first Wright Glider. It was tested in October 1900 at Kitty Hawk, NC, where although lifting off the ground, it produced disappointing results.

The Wright brothers refined their glider and tested it in 1901, then again in October 1902 after spending the summer undertaking a vast series of tests into more efficient wing designs. This third model was the breakthrough, with the glider performing exactly as predicted. The pair – who each piloted the glider in turn – racked up almost 1,000 flights between them over a two-month period, covering distances at Kitty Hawk of up to 190 metres (622 feet).

Realising they had cracked both the aerodynamic and control issues that all of

The big idea

Prior to the Wright brothers' successful flight (pictured below), many other scientists and engineers had dreamed about and, to varying degrees of failure, attempted to build machines that could not only defy gravity, but do so in a controlled manner. Their failures left the idea of a non-dirigible method of flight as mere fancy, with materials, aerodynamics and energy supplies all seeming insurmountable obstacles.

What is testament to the Wright brothers' expertise is that they addressed each one of these issues with their aircraft in turn, solving in years what countless minds had failed to address in centuries. Examples include the testing of hundreds of wing designs in a custom-built wind tunnel to determine which shape best granted lift, designing and building their own four-cylinder internal combustion engine that was adapted for air travel and recognising that propeller blades could be understood as rotary wings.

A life's work

The main milestones that led to the Wright Flyer taking off…

1867
Wilbur is born, with Orville arriving four years later.

1869
The Wright family move to Dayton, OH, due to the father's work commitments.

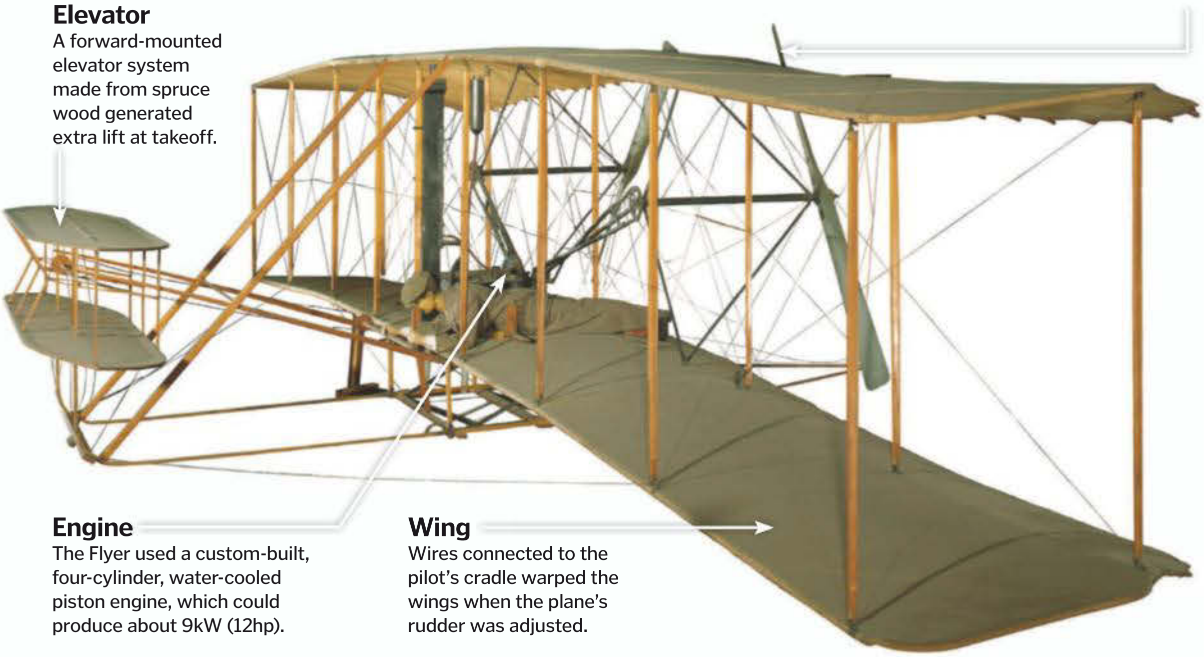
1892
Both brothers team up to open a bicycle repair shop. They begin building bikes a few years later.

1900
Years of research lead to the brothers testing the Wright Glider (right), an unpowered biplane with a forward elevator for pitch control.

DID YOU KNOW? *Orville Wright was a troublemaker as a child, and once was expelled from elementary school*

The Wright Flyer in focus

Take a closer look at the pinnacle of the Wright brothers' aviation careers



Elevator
A forward-mounted elevator system made from spruce wood generated extra lift at takeoff.

Propeller
Two large propellers were driven by a sprocket chain drive, granting the Flyer a small amount of thrust.

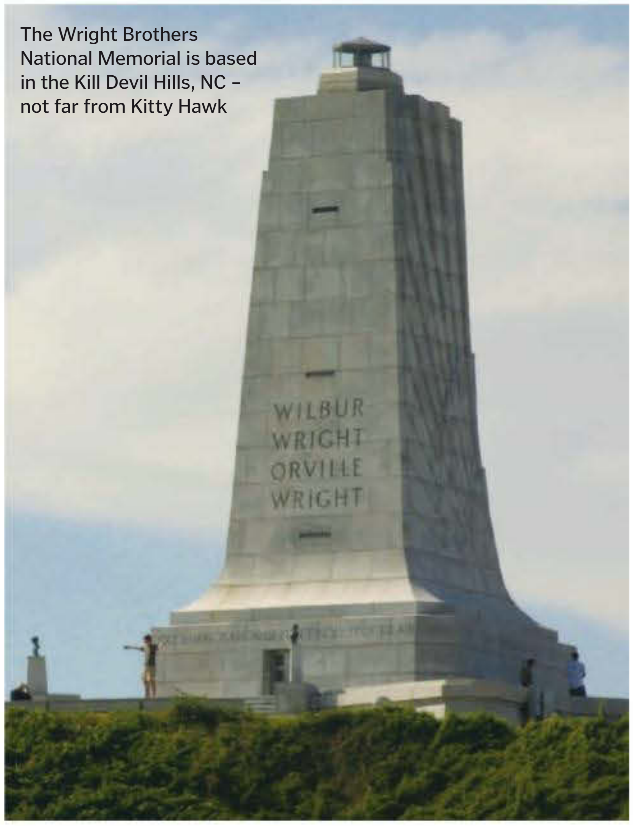
Engine
The Flyer used a custom-built, four-cylinder, water-cooled piston engine, which could produce about 9kW (12hp).

Wing
Wires connected to the pilot's cradle warped the wings when the plane's rudder was adjusted.

their predecessors had struggled with, the two brothers turned their attention to a powerplant for the glider. In 1903 they built their own four-cylinder internal combustion engine and returned to Kitty Hawk to trial it. Unfortunately the first attempt ended in the engine stalling during takeoff and the front of the plane getting damaged, but after a couple of repairs, the second flight ended in resounding success.

Lifting off at 10.35am on 17 December 1903, the Wright Flyer flew 36 metres (120 feet), then 53 metres (175 feet), followed by 60 metres (200 feet) and finally 259.7 metres (852 feet). This series of flights heralded a new era of aviation and propelled the Wright brothers and their aeroplane to worldwide fame.

> *"The brothers became well known for their academic and practical application of modern engineering"*



The Wright Brothers National Memorial is based in the Kill Devil Hills, NC – not far from Kitty Hawk

Five facts: Wright bros

1 No college

Wilbur and Orville were the only members of the Wright family who didn't attend college. Orville spent the years learning the printing trade, while Wilbur helped out at the local church.

2 Lifelong bachelors

Neither of the Wright brothers married throughout their lives. Wilbur is recorded as once saying that he "did not have time for both a wife and an airplane."

3 Child's play

In their later lives, the Wright brothers attributed their fascination with flying machines to a small toy helicopter which their father had brought home one day from his travels.

4 Luminaries

Both of the brothers extensively catalogued their aviation experiments on paper, leading to Wilbur Wright delivering an official talk at the highly prestigious Western Society of Engineers in Chicago in 1901. The speech he held was entitled 'Some Aeronautical Experiments'.

5 Hobby to business

In 1909 the Wright Company was incorporated with Wilbur as president and Orville as one of two vice-presidents. Orville sold the company three years after Wilbur's death in 1912.

© Thinkstock; Getty

1903
The brothers successfully fly the Wright Flyer in sustained flight at Kitty Hawk, NC. Its fourth flight covers 259.7 metres (852 feet) in just 59 seconds.

1909
The Wright Company sells the first-ever military aircraft, the Wright Military Flyer (right), to the US Army Signal Corps.

1912
Wilbur dies of typhoid fever on 30 May at 45 years old.

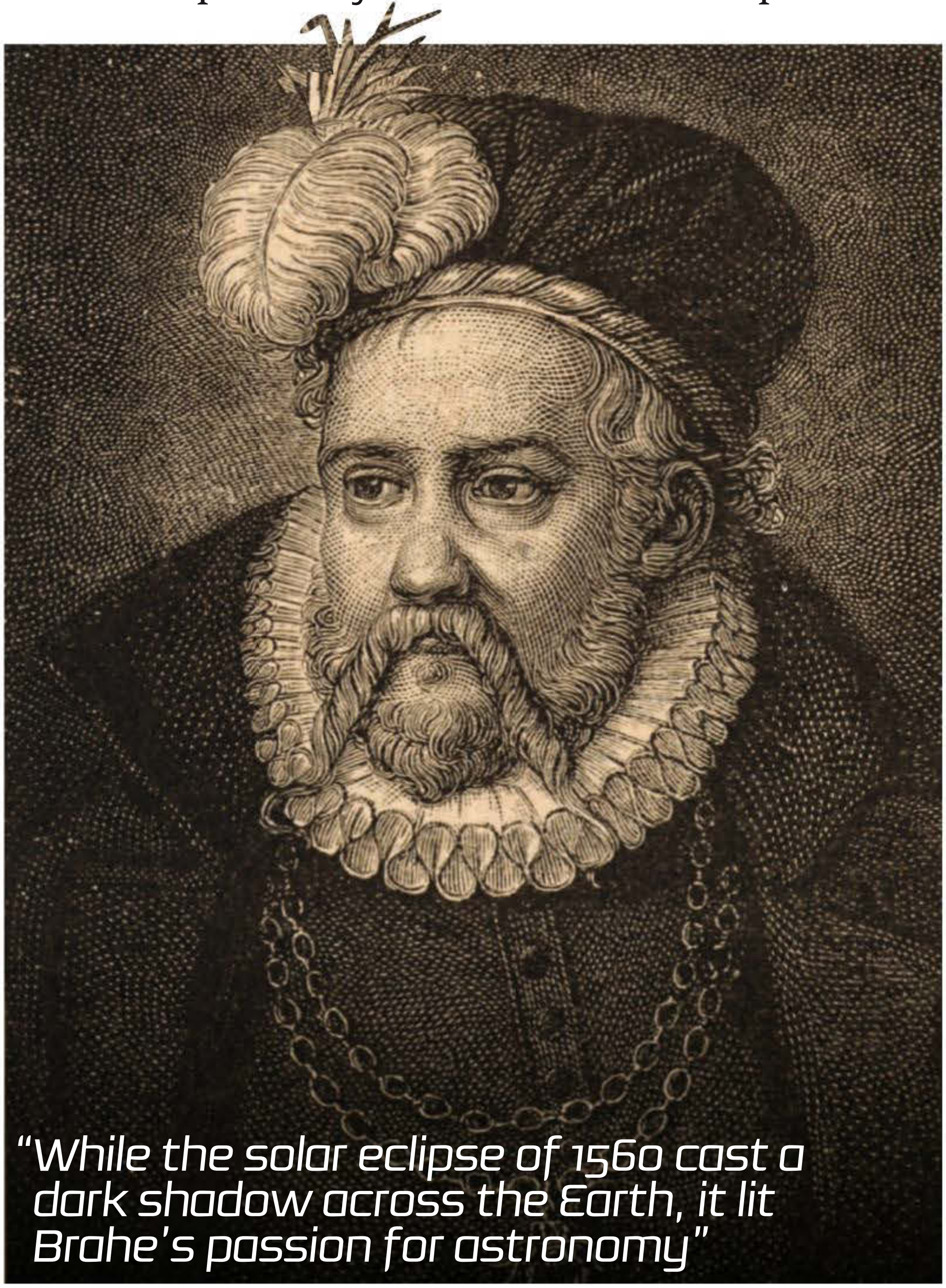
1915
Orville ends his leadership of the Wright Company by selling his shares to a group of financiers.

1920
Orville joins the board of the National Advisory Committee for Aeronautics – a precursor to NASA.

1948
Orville suffers a heart attack on 27 January and dies three days later in Dayton, OH, aged 76.

Tycho Brahe

Meet the man who coined the term 'nova' and calculated planetary motion before telescopes

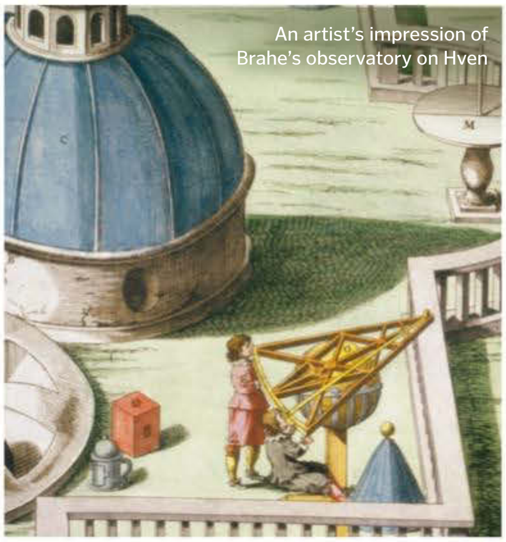


"While the solar eclipse of 1560 cast a dark shadow across the Earth, it lit Brahe's passion for astronomy"

Few other naked-eye astronomers have plotted the movement of planets quite as accurately as Danish nobleman Tycho Brahe. His observations of a new star in 1572 and the Great Comet of 1577 helped to shake off the Aristotelian belief that the planets and stars were unchanging and locked in 'immutable' celestial spheres.

Brahe's schooling began at an early age. Indeed, at just two years old, he was taken from the family home by his uncle to start his education. At age 12, he began studying law at the University of Copenhagen, as was the norm for sons of nobility. However, while the solar eclipse of 1560 cast a dark shadow across the Earth, it lit Brahe's passion for astronomy, and he emerged himself in the works of the great astronomers of the time.

For some time Brahe studied abroad, but upon his return another uncle – Steen Bille – funded the construction of an observatory and chemical laboratory at Herrevad Abbey. It was here in 1572 that he first noticed the appearance of a very bright star. At the time, the popular theory was that the planets and stars were carried on material spheres (spherical shells) that fitted tightly around each other. Brahe's observations proved that his sighting was indeed a new star and not a local phenomenon, and therefore this arrangement was impossible. A year later he published his first book – *De Nova Et Nullius Aevi Memoria Prius Visa Stella* (*On The New And Never Previously Seen Star*) –



An artist's impression of Brahe's observatory on Hven

A life's work

A quick guide to Tycho Brahe's illustrious career as an astronomer

1546
Tycho Brahe is born at Knutstorp Castle in the then-Danish Scania, to nobleman Otte Brahe and his wife Beate Bille.

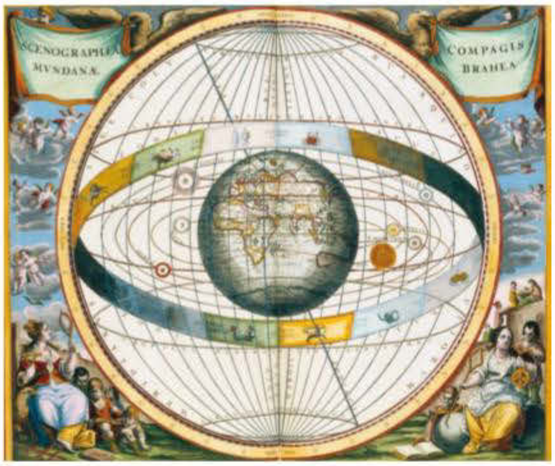
1559
Brahe begins his studies in law at the University of Copenhagen.

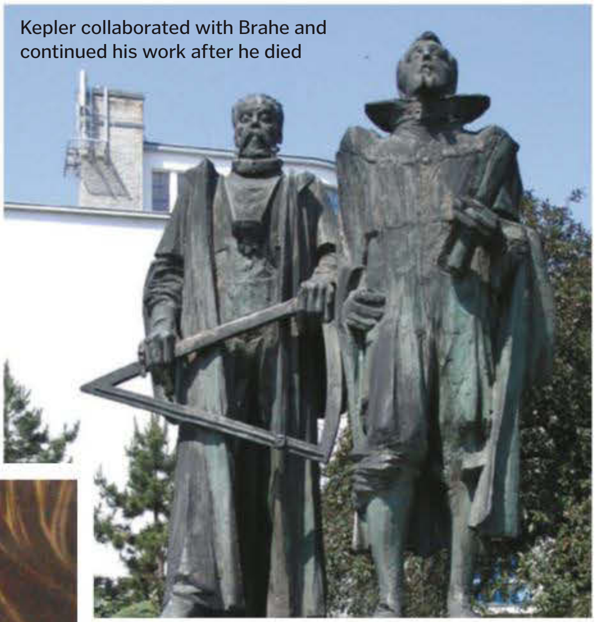
1560
The prediction of a solar eclipse occurring on 21 August 1560 impresses Brahe enormously, and soon inspires him to study astronomy.

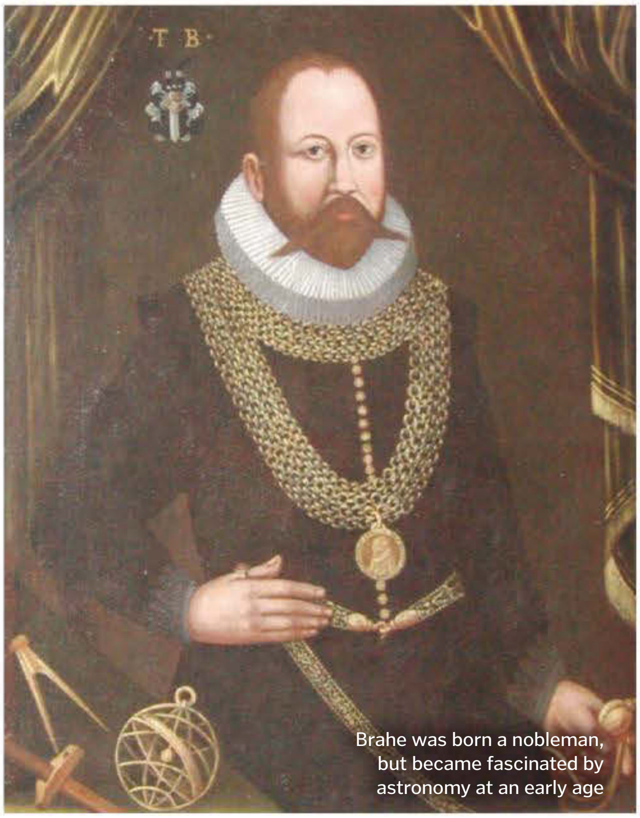
1572
Brahe first observes a new star, now known as SN 1572, from the Herrevad Abbey observatory.

1573
Brahe publishes his book, *De Nova Stella*, coining the term 'nova' for a new star.

DID YOU KNOW? *There is much speculation that Brahe's life and work provided inspiration for Shakespeare's Hamlet*



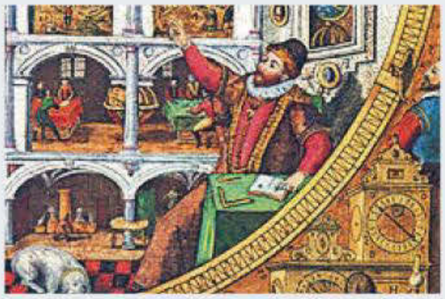

Kepler collaborated with Brahe and continued his work after he died



Brahe was born a nobleman, but became fascinated by astronomy at an early age

The Tychonic system

The Tychonic system is a model of the Solar System developed by Brahe. Unlike Copernicus's heliocentric model (with the Sun at the centre), he believed that Earth was too 'hulking' and 'lazy' to be continuously in motion. Religion also played a part in Brahe's rejection of heliocentrism, and cited the Bible in his work. Instead, he suggested a 'geo-heliocentric' model in which the Earth is at the centre of the universe, with the Sun and Moon orbiting the Earth and the other planets orbiting the Sun.



Five facts: Tycho Brahe

1 Naked eye

Brahe was the last of the major naked-eye astronomers, as it wasn't until seven years after his death that the first telescopes came into use.

2 Hard nosed

At the age of 19, Brahe lost the bridge of his nose in a sword fight with a fellow student. For the rest of his life he wore a metal prosthesis to hide the injury.

3 Tycho the tyrant?

It is rumoured that Brahe led an extremely oppressive regime on the island of Hven, and that he was deeply despised by the people under his rule there.

4 Murder mystery

It was suggested that Brahe had been poisoned, but after being exhumed from his grave in 2010, results indicated that he probably died from a burst bladder or something similar.

5 Lunar legacy

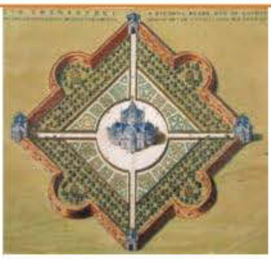
Craters Tycho on the Moon and Tycho Brahe on Mars are named after Brahe.

and it was from this that the term 'nova' came into common use to describe a new star.

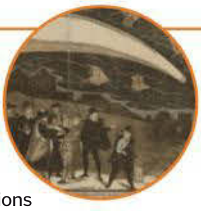
After another tour abroad, King Frederick II, desperate to keep Brahe in Denmark, offered him the island of Hven and funding to set up another observatory. In 1576 Uraniborg was built, and later an underground observatory called Stjerneborg. As well as being observatories, they also functioned as workshops where Brahe designed and built new instruments. He was able to make incredibly accurate observations – they were said to be more accurate than any before.

After King Frederick's death in 1588, Brahe's popularity declined. In 1599, after falling out with King Christian IV, Brahe moved to Prague (then part of Bohemia). Sponsored by Bohemian king Rudolph II, he built a new observatory at Benátky nad Jizerou. Here he was responsible for compiling the Rudolphine Tables – astronomical tables that allowed calculations of the planetary positions for any time in the past or future. Here Brahe's assistant was Johannes Kepler. Brahe entrusted the continuation of his extensive research to Kepler after his death in 1601, who published the finished astronomical tables 26 years later.

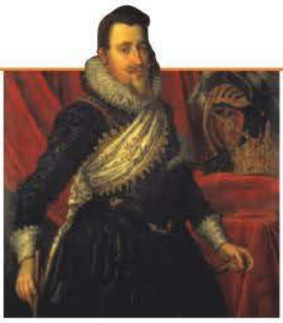
1576
King Frederick II of Denmark offers Brahe the island of Hven, where he builds the Uraniborg observatory.



1577
Brahe's observations of the Great Comet (above) prove that objects can move through the celestial spheres.



1599
After a disagreement with the new Danish king Christian IV (right), Brahe moves to Prague, becoming Bohemia's official imperial astronomer.



1601
Brahe suddenly contracts a kidney or bladder ailment and dies 11 days later, aged 54.

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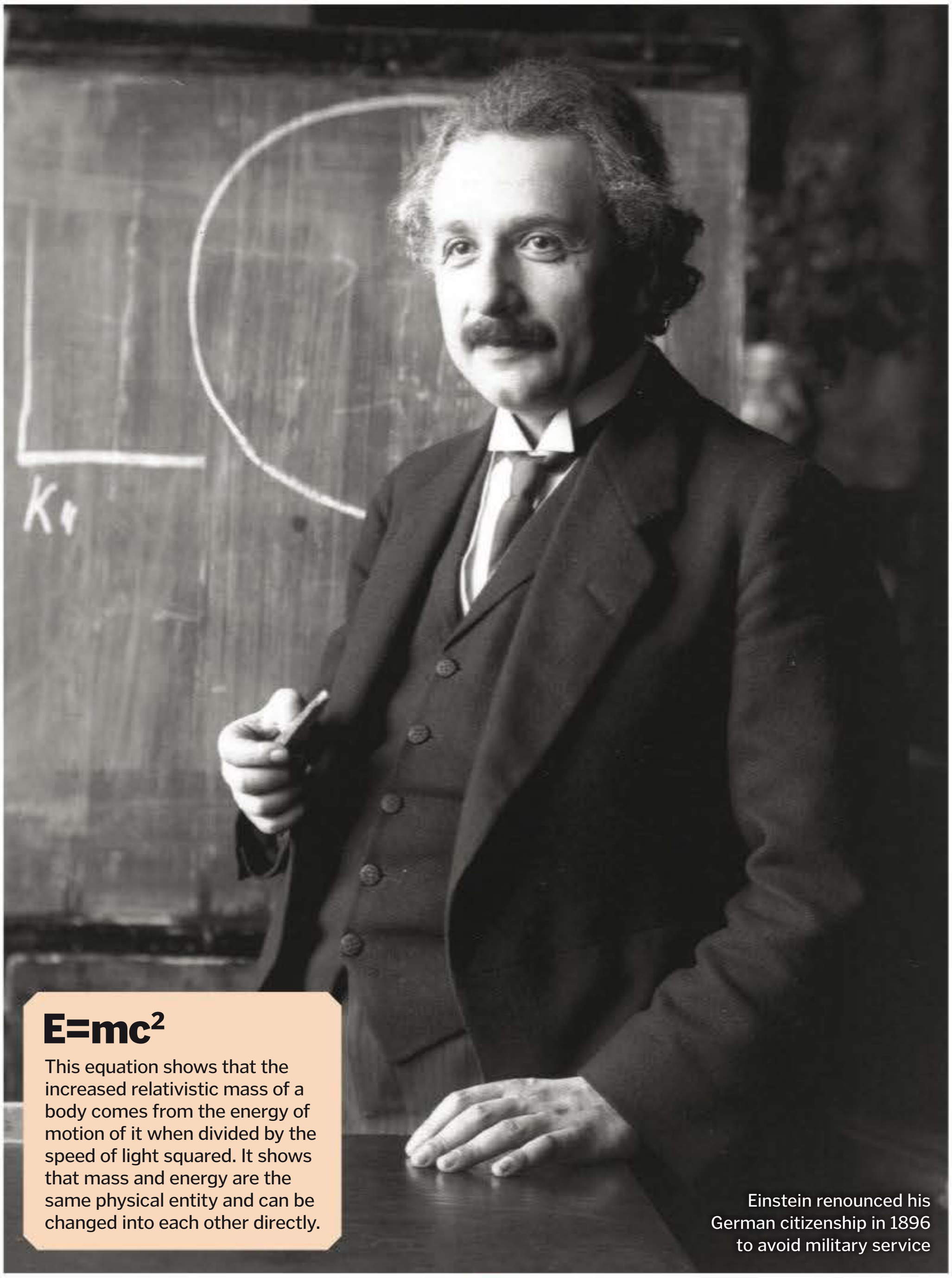
Albert Einstein

The foremost scientist of his age, Einstein is considered the most influential physicist of all time



E=mc²

This equation shows that the increased relativistic mass of a body comes from the energy of motion of it when divided by the speed of light squared. It shows that mass and energy are the same physical entity and can be changed into each other directly.

Einstein renounced his German citizenship in 1896 to avoid military service

Albert Einstein was born on 14 March 1879, in Ulm, Germany. He is considered the most influential physicist of the 20th Century, formulating both the theories of special and general relativity, concepts that still underpin much in the fields of physics and astrophysics today. In 1921 he was awarded the prestigious Nobel Prize in Physics for his explanation of the photoelectric effect – a process where electrically charged particles are released from a substance when exposed to electromagnetic radiation.

Einstein's first real contact with science came when he was a young boy, instigated by his intrigue with his father's compass. Confused by the invisible forces that seemed to be acting upon the needle, he went through his early years fascinated by such forces. Spurred on by reading the work of Aaron Bernstein, which introduced him to the concepts of electricity and light, Einstein dedicated his later teenage years to the nature of light, writing a scientific paper entitled 'The Investigation Of The State Of Aether In Magnetic Fields'.

Despite a great love for the sciences, Einstein had a troubled education. He skipped classes while attending the Swiss Federal Polytechnic School, and his father's failed business led to much disruption, with Einstein having to move frequently. This led to a period where he was forced to take a position at the Swiss patent office in Bern, a role significantly less prestigious than his desired doctorate.

In hindsight, though, the position at the patent office was ideal, as the work left much time for him to theorise on the properties and nature of light. Then, suddenly, in 1905 Einstein made a breakthrough, starting what is now termed his 'miracle year'. In that time he published four papers: the first on the photoelectric effect, the second on the existence of atoms, the third introducing the

A life's work

We chart Einstein's phenomenal journey to becoming the most influential physicist

1879

Einstein is born on 14 March in Ulm, Germany.

1896

After avoiding military service, Einstein enrolled in a four-year mathematics and physics teaching course in Zurich.

1905

Einstein released four papers on the photoelectric effect, Brownian motion, special relativity and the equivalence of matter and energy.

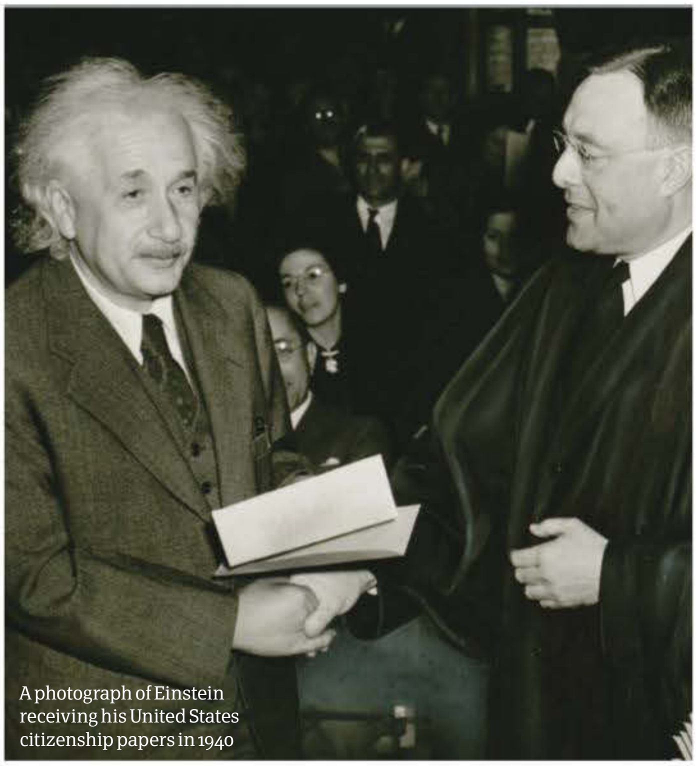
1906

Einstein receives a doctoral degree from the University of Zurich.

1908

He becomes lecturer at the University of Bern.

DID YOU KNOW? *Einstein had an illegitimate daughter, who was born in 1902*


A photograph of Einstein receiving his United States citizenship papers in 1940

Einstein's former summer home in Germany was confiscated by the Nazis and is currently the subject of a legal battle over its ownership

mathematical theory of special relativity and the fourth on the theory of relativity. Famously, Einstein published the last paper almost as an afterthought, despite it containing the key equation for which he is famous: E=mc2.

At first the scientific establishment ignored Einstein's papers. Fortunately, though, they caught the attention of the foremost scientist of the age: Max Planck, the founder of quantum theory. Through Planck, Einstein became a respected member of the international community, attending the prestigious Solvay conferences and being offered important positions at Europe's foremost universities.

After completing his theory of general relativity in November 1915, Einstein's work was interrupted by World War I. Being a life-long pacifist, Einstein opposed the war and spoke frequently on its folly. After its conclusion, Einstein toured the world, but his period away from Europe was soon to be made permanent, with Einstein fleeing Nazi Germany in 1933. He settled in America and was granted US citizenship in 1940.

While in America, though he was not immediately convinced that an atomic bomb was possible, Einstein had encouraged the US government, including personally writing to President Roosevelt, to research nuclear chain reactions using uranium in response to German advances in the field. He did not work directly on the project to build a bomb, despite it being heavily based on his own work. According to reports, Einstein was on vacation when the first atomic bomb was dropped on Hiroshima, Japan. This action and its aftermath led to him undertaking anti-nuclear campaigns and lectures for the rest of his life.

Einstein's later years saw him pioneer numerous key theories including wormholes, multi-dimensional models and the possibility of time travel, as well as discovering his unified field theory. The latter was to be an all-embracing theory that would unify the forces of the universe and physics into one framework. The theory was never completed, however, with Einstein dying of an aortic aneurysm in 1955 before being able to finish his work.

Five facts: Einstein

1 Boy of few words

According to reports, Einstein seldom spoke as a child and when he did, it was very slowly. Accounts state he did this until he was nine.

2 Point of inspiration

Einstein's interest in science was reportedly sparked by his father's compass. At the age of five he thought there must be some force in the apparently empty space that acted on the needle.

3 Slow to start

Einstein did not receive outstanding grades while at school, and when he left he flunked the entry exam for the polytechnic institute in Zurich. Instead he went to work in the Swiss patent office first.

4 Nuclear pacifist

Einstein was a pacifist and while initially supporting the use of atomic weapons as a deterrent, he later chose to campaign for nuclear disarmament and world peace.

5 Man with two brains

After his death in 1955, Einstein's brain was removed for preservation by Thomas Stoltz Harvey in an attempt to discover what made him so intelligent.

> *"In 1905 Einstein made a breakthrough, starting his 'miracle year'"*

1911
Einstein moves to Prague, where he acts as professor at the Karl-Ferdinand University.

1912
Einstein moves back to Switzerland, taking up a professorship at his alma mater, the Swiss Federal Institute of Technology in Zurich.

1915
Einstein completes his general theory of relativity.

1919
A solar eclipse provides dramatic observable evidence that his general theory of relativity is correct, making him a worldwide celebrity.

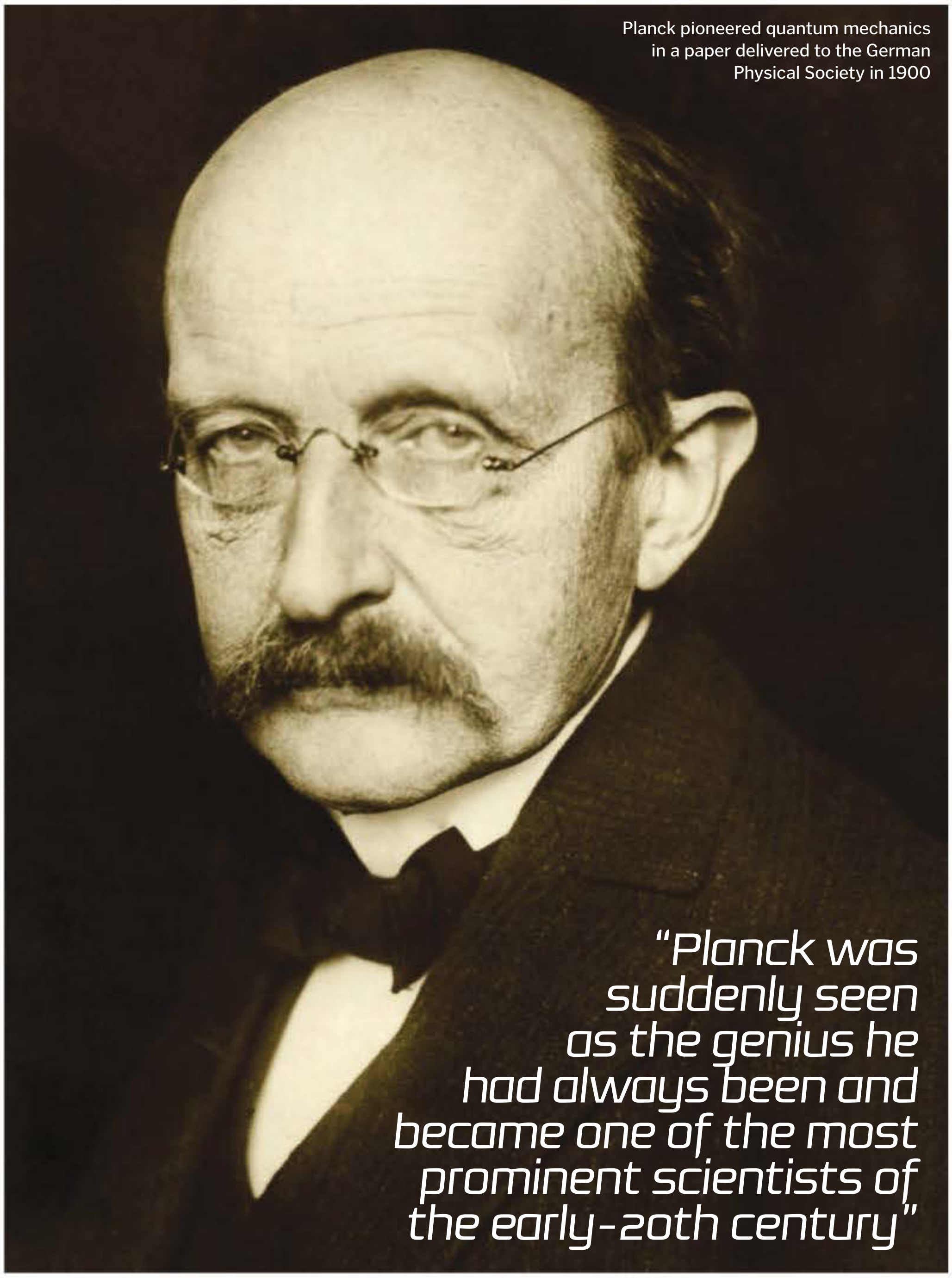
1921
16 years after its publication in 1905, Einstein wins the Nobel Prize in Physics for his work on the photoelectric effect.

1933
Einstein and his family flee from Nazi Germany to settle in the United States. He works at the Institute of Advanced Study at Princeton.

© Roland zh; NASA

Max Planck

The father of quantum physics, Max Planck was one of the foremost theoretical physicists of the 20th century whose work ushered in a new era of science



Planck pioneered quantum mechanics in a paper delivered to the German Physical Society in 1900

> "Planck was suddenly seen as the genius he had always been and became one of the most prominent scientists of the early-20th century"

If you had to choose two scientists of the 20th century whose work most affected its course and discoveries, the first would no doubt be Albert Einstein, but the second could be Max Planck. Einstein's theory of relativity revolutionised how humans perceived and understood space and time, while theoretical physicist Planck's development of quantum theory, with his probing work into atomic and subatomic processes, radically transformed how physics was understood and directly led to many other discoveries and inventions that still have a widespread impact today.

Easily Max Planck's most important discovery was his realisation that the energy of electromagnetic waves is contained within indivisible 'quanta' packets that have to be radiated or absorbed as a whole. This is commonly referred to as Planck's black-body radiation law and, as can be seen in detail within 'The big idea' boxout explanation, it is both simple and incredibly enlightening. However, when Planck delivered his research for the first time in 1900, it was anything but, with its suggestions seemingly conflicting directly with all of classical physics. Indeed, even Planck himself did not fully believe his law was correct, only reluctantly deducing it through a cold sense of logic.

His remarkable discovery was not recognised either by the existing scientific establishment, with recognition only coming after Einstein himself adopted the idea of quanta and later introduced the follow-on theory of wave-particle duality in 1909. Following this, Planck was suddenly seen as the genius he had always been and became one of the most prominent scientists of the early-20th century, attending among numerous others, the celebrated Solvay Conference in Brussels in 1911.

Indeed, famously it was due to Planck's input at the conference that Henri Poincaré –

A life's work

Events that sculpted the life of one of the 20th century's leading physicists

1858
He is born Max Karl Ernst Ludwig Planck in Kiel, the Duchy of Holstein in the German Confederation.

1864
Experiences war first hand as Prussian and Austrian troops march through Kiel during the Second Schleswig War.

1878
After graduating early from the Maximilians school in Munich, he travels to Berlin to study, passing his exams with flying colours.

1880
Planck presents his habilitation thesis entitled Equilibrium States Of Isotropic Bodies At Different Temperatures and becomes a private lecturer in Munich.

1885
Planck is appointed associate professor of theoretical physics at the University of Kiel.

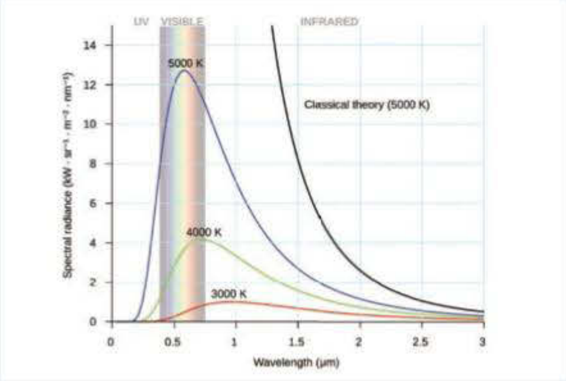
Max Planck working in his study in 1918 – the year he was awarded the Nobel Prize in Physics

the most famous mathematical physicist of the 19th century – could provide mathematical proof that Planck's radiation law required the existence of quanta and, as a knock-on effect, converted many of Europe's top scientists to this new quantum theory.

And so quantum theory was born, and over the following decades it was built upon and expanded by some of the most well-known scientists of all time. From Einstein to Niels Bohr, Erwin Schrödinger to Paul Dirac, Planck – as the father of quantum theory – had given them an entirely new way to look at and understand the processes of the physical world – one which they would go on to explore in much more detail through the nuclear age.

The big idea

Planck's law is a mathematical relationship formula created in 1900 by Max Planck to explain the spectral-energy distribution of radiation emitted by an idealised black-body phenomenon. Key was Planck's assumption that sources of radiation are atoms in a state of oscillation and that the vibrational energy of each atomic oscillator may have a series of discrete values but never any fixed value between. This discovery, along with the ground-breaking work of Albert Einstein, led directly to the end of the age of classical physics.



Five facts: Max Planck

1 Name change

Max Planck was born Karl Ernst Ludwig Marx Planck, but by the age of ten he began signing his name as simply 'Max'. He would continue to use this for the rest of his life, largely abandoning his other forenames.

2 Special theory

Max Planck was one of the first physicists to understand the importance of Albert Einstein's theory of relativity, using his influence to promote the young Einstein's seminal work and expand upon it.

3 Manifesto

Max Planck was one of the German scientists who signed the Manifesto of the Ninety-Three, a 1914 proclamation that supported the German military actions in the early period of World War I. He later regretted signing the declaration.

4 Highest authority

After World War I Planck was considered the highest scientific authority in the whole of Germany and consequently held positions at Berlin University, the Prussian Academy of Sciences and the German Physical Society.

5 Resistant

During WWII Planck was one of few scientists to stay in Nazi-led Germany. His son Erwin was involved in the Hitler assassination attempt.

1892
After years of lecturing, Planck is made full professor at the prestigious University of Berlin.

1900
Planck outlines for the first time his famous black-body radiation law to the German Physical Society.

1918
Max Planck receives the Nobel Prize in Physics for his groundbreaking work on quantum theory.

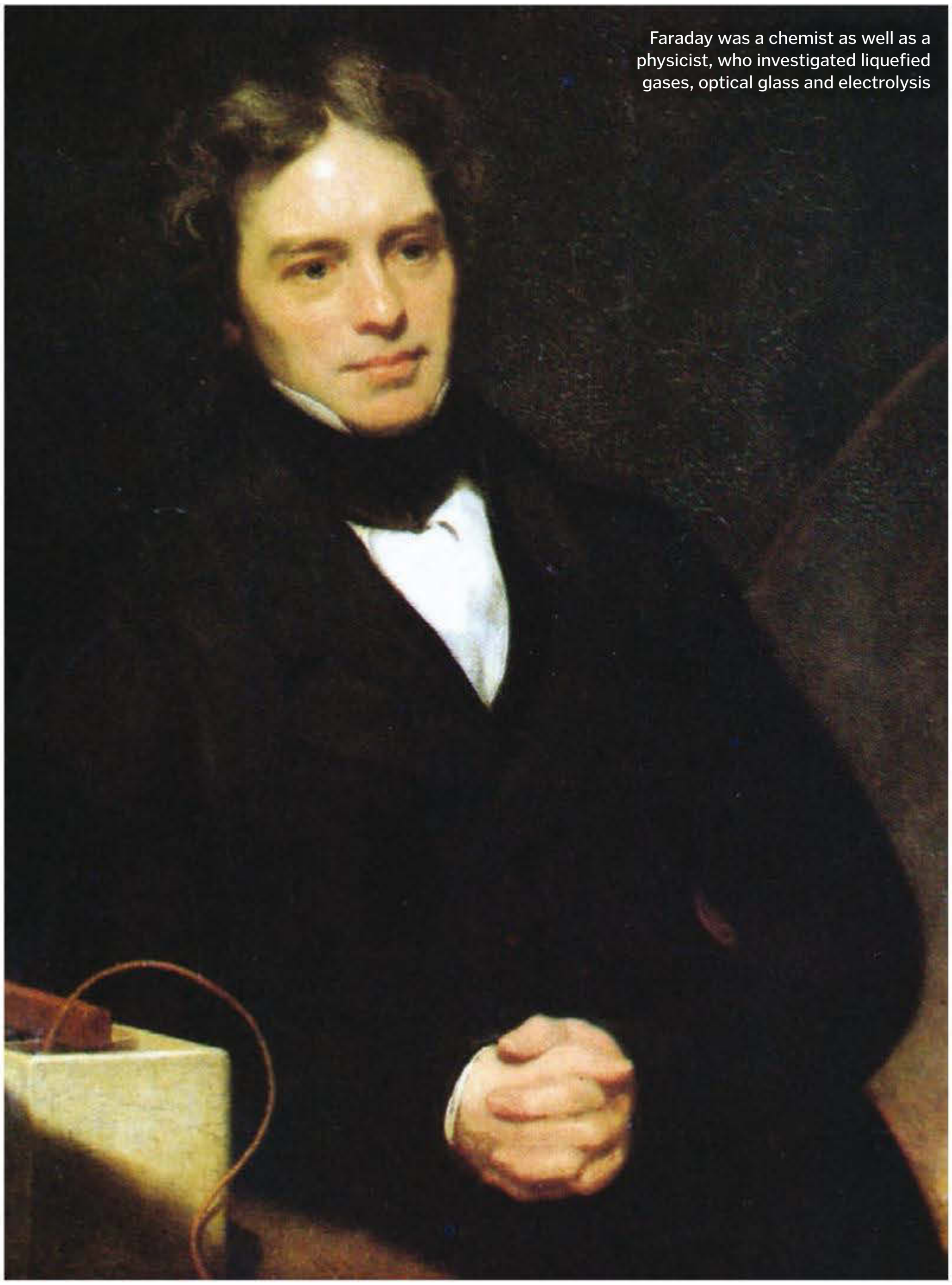
1928
The German Physical Society creates the Max Planck medal and enshrines it as the highest accolade that they can bestow.

1947
Max dies at the age of 89 in his last home situated in Göttingen, Germany.

© Corbis

Michael Faraday

The scientist behind electromagnetic induction who played a key role in inspiring Einstein…



Faraday was a chemist as well as a physicist, who investigated liquefied gases, optical glass and electrolysis

Michael Faraday was born in 1791 to a poor family who couldn't afford to educate him. Few could have guessed that he would go on to massively advance our understanding of electricity and more. He learned to read and write at Sunday school, and subsequently became a bookbinder's apprentice in his teens.

Faraday loved to read and he worked his way through the books that he was binding, developing a keen interest in chemistry, electricity and magnetism. His newfound interest in science led him to attend a series of four lectures by chemist Humphry Davy, where he took extensive notes in the hope of securing employment at the Royal Institution. Eventually, his persistence paid off and he managed to get a job working as a laboratory assistant to Professor Davy.

Faraday worked for Davy for several years, during which time the pair travelled to Europe for their research. While with Davy, Faraday made several discoveries in the field of chemistry, including identification of the ring-shaped hydrocarbon benzene. He also made two new chemical compounds: hexachloroethane, which now forms the basis of military smoke grenades, and tetrachloroethylene, which is widely used to dry-clean clothes even to this day.

Faraday's major breakthroughs were not in chemistry though, but in physics. In 1820, Hans Christian Oersted discovered that an electrical current could produce a magnetic field. Faraday was convinced that the opposite must also be true, and began his most influential work on electromagnetic induction. His first discovery came shortly after, when he showed that by wrapping two insulated coils of wire around an iron ring a current could be transferred from one coil to another in a process known as mutual inductance.

Keen to further this research, Faraday continued investigating the electromagnetic properties of materials, and this led to his greatest achievement of all in 1831 – the discovery of electromagnetic induction (see 'The big idea' for more information).

Faraday's work on electromagnetism sparked the interest of other scientists and

A life's work

We highlight some key events from Faraday's electrifying career in the 19th century

1791
Michael Faraday is born in Surrey, UK, to James Faraday and Margaret Hastwell.

1805
Faraday starts work as a bookbinder's apprentice. During this time he develops an interest in science.

1813
He works as assistant to Professor Humphry Davy, making several advances in the field.

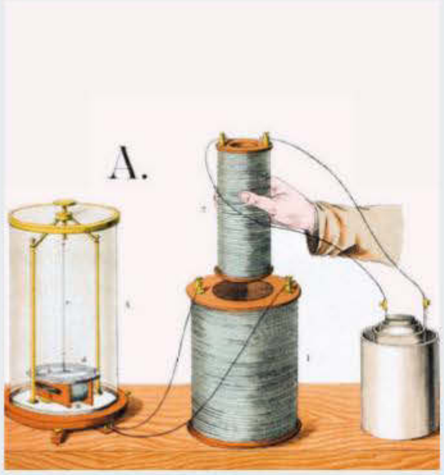
1821
Faraday discovers the principle behind the electric motor, using the idea of electromagnetic rotation.

1824
He is elected a fellow of the Royal Society.

DID YOU KNOW? *Due to family money contstraints Faraday left school at the age of 13 to earn money*

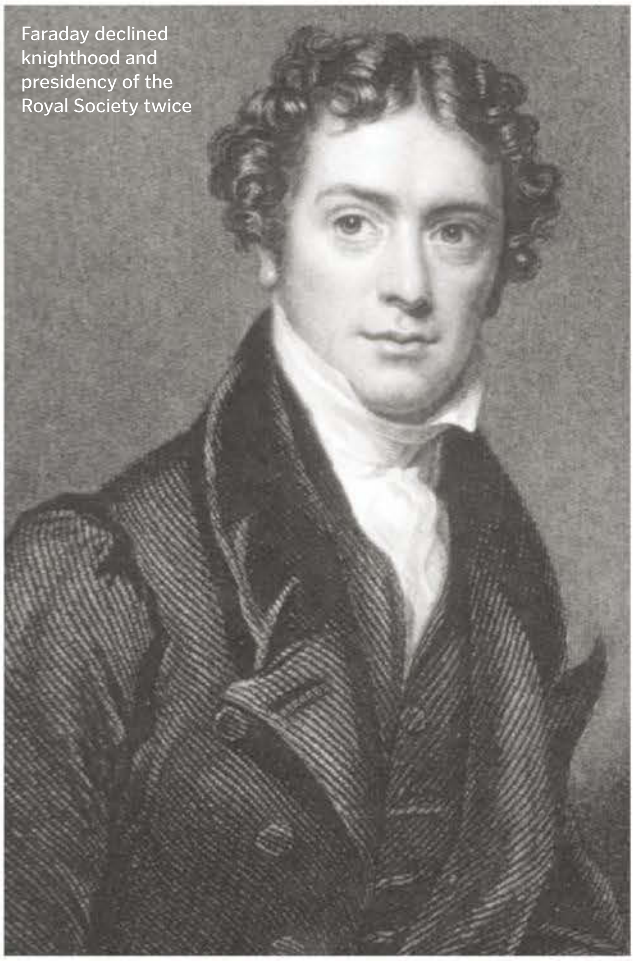
The big idea

Faraday was a prolific scientist, but is best known for his work on electromagnetic induction. Faraday's Law states that a change in the magnetic environment near to a coil of wire will induce a voltage in the coil. Faraday developed a spinning copper disc, which rotates next to a static magnetic field (provided by a bar magnet). As the disc spins through the magnetic field, a potential difference is generated between the centre and the edge of the disc, creating a steady direct current. Faraday's disc was inefficient, but it provided the basis for the development of transformers, inductors, electrical motors and generators.

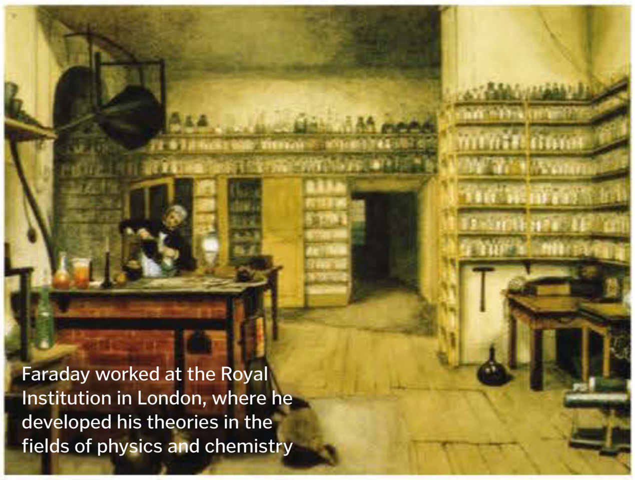


mathematicians, which led to William Thomson writing to him, suggesting that it was mathematically possible for magnets to alter the plane of polarised light. Faraday had been interested in this idea himself for a very long time, conducting experiments to show how light and magnetic fields interact with each other. This was one of the first steps towards the realisation that visible light is actually electromagnetic radiation.

Later in life Faraday's health declined, but even so, he stubbornly continued his lecturing at the Royal Institution. His incredible scientific contributions were officially acknowledged by the royal family and, in 1858, Faraday moved to a home in Hampton Court, granted to him by Queen Victoria. He died in 1867 and, having previously refused a burial site at Westminster Abbey, he was buried in Highgate Cemetery instead.



Faraday declined knighthood and presidency of the Royal Society twice



Faraday worked at the Royal Institution in London, where he developed his theories in the fields of physics and chemistry

Five facts: Michael Faraday

1 No one-trick pony

Faraday developed an early version of the Bunsen burner and also discovered the laws of electrolysis.

2 Nanoparticles

Faraday was the first to report nanoparticles' properties, noticing that gold colloids (sub-micrometre-sized gold particles dispersed in a liquid) have different properties to solid gold.

3 Modest man

He declined a knighthood offered by Queen Victoria, and refused to accept presidency of the Royal Society twice.

4 Christmas Lectures

Faraday founded the Royal Institution's (RI) Christmas Lectures. To this day, fun science demonstrations for children are broadcast every Christmas in the UK by the RI.

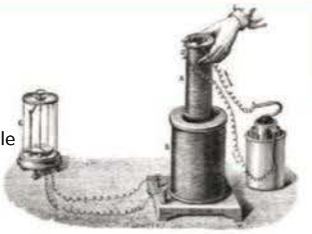
5 Competition

The Italian priest Francesco Zantedeschi and US scientist Joseph Henry were both working on electromagnetic induction too. Which of these men came up with the idea first is still contested to this day.

> *"Faraday worked his way through the books that he was binding, gaining interest in chemistry, electricity and magnetism"*

1825
Faraday is appointed director of the laboratory at the Royal Institution, beginning the Christmas Lecture series.

1831
He discovers the principle of electromagnetic induction and invents the electromagnetic generator.



1858
Faraday moves to Hampton Court, awarded to him by Queen Victoria for his services to science.

1867
Faraday dies, aged 75, at his home in Hampton Court. He is buried in Highgate Cemetery.

MICHAEL FARADAY
BORN 22 SEPTEMBER
1791
DIED 25 AUGUST
1867
SARAH HIS WIFE
BORN 7 JANUARY
1800
DIED 6 JANUARY
1879

© Corbis

Alfred Nobel

After exploding into the history books, this Swede sought to leave an academic legacy

Few scientists have left a legacy more noble than Alfred Nobel. This Swedish chemist not only invented dynamite, but also urged other scientists to explore new avenues of study by establishing the world's most prestigious accolade for intellectual achievement: the Nobel prize.

Since the award was founded in 1901, the greatest minds have been rewarded for their services to the advancement of science and other arts. This peer-assessed award, Nobel hoped, would inspire people to push the boundaries for the benefit of humanity. Past winners include such geniuses as Albert Einstein, Marie Curie and Alexander Fleming.

Alfred Bernhard Nobel was born in Stockholm, Sweden, on 21 October 1833 to Immanuel and Andriette. His mechanical engineer father enjoyed varying degrees of success with a number of inventing and manufacturing business ventures. In 1837, however, Immanuel left in search of better fortune in Russia. By 1842 he had established a profitable business producing equipment for the Russian military, and so the rest of the Nobel family moved out to join him.

Together with his three brothers – Robert, Ludwig and Emil – Alfred was home-educated by private tutors. Taking a cue from his entrepreneurial father, who also designed and made mines, Alfred developed a talent for chemistry – and explosives in particular. In 1850 Alfred travelled to Paris to study chemistry under French professor Théophile-Jules Pelouze, who had been carrying out experiments using concentrated nitric acid to develop explosive materials in his laboratory.

On his return to Russia Nobel began working in his father's factory manufacturing military equipment for the Crimean War. Once the conflict was over in 1856, however, the company struggled to turn a profit and, by 1859, the firm had gone bust, forcing the Nobels to return to Sweden. Alfred's two elder brothers, Robert and Ludwig, remained in Russia with hopes of salvaging what was left of the business.

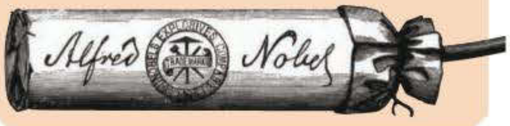
Alfred, meanwhile, started experimenting with explosives in his father's lab. By 1862 he had set up a small factory in which he began to manufacture an exciting but highly volatile explosive called nitroglycerin, which had recently been invented by another of Pelouze's students: Ascanio Sobrero. While Nobel recognised the industrial potential of this explosive, the use of nitroglycerin was just not practical due to its unstable nature. The challenge was to find a way to control nitroglycerin so it could be safely handled.

Nobel spent many years perfecting the formula for his explosives, as well as inventing and developing detonation devices. Eventually his research led him to discover a way to make nitroglycerin stable and practical for the construction and mining industries. This development was the invention of dynamite (see 'The big idea' boxout), for which Nobel obtained the patent in 1867. With a commercial product on his hands, Nobel became a

The big idea

Nobel's work with nitroglycerin led him to experiment with different additives to stabilise the oily liquid. One of Nobel's early 'big ideas' was the invention of a functioning detonator, which he designed first as a simple wooden plug and developed into the patented blasting cap, which was fitted with a small primary charge that could be detonated by a strong shock. While the detonators were groundbreaking, it was Alfred's chemistry that really put him on the map.

To make nitroglycerin safer, Nobel spent years developing the formula; several labs and factories were blown up in the process! Before long he discovered that by adding a very fine inert silica powder called diatomaceous earth, or kieselguhr, the oily nitroglycerin liquid could be transformed into a safer, malleable paste. When shaped into rods, this paste could be inserted into drilling holes and detonated in order to blast rock for mining. And the name of this material? Dynamite.



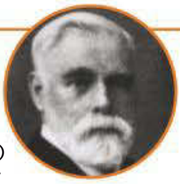
> "He bequeathed much of his wealth to the establishment of an annual prize that he hoped would stimulate scientific progress"

A life's work

The explosive timeline of the inventor of dynamite

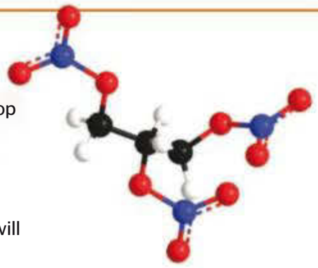
1833
Alfred Bernhard Nobel is born in Stockholm, Sweden, on 21 October.

1837
Nobel's father (right) moves away from the family to Finland and then St Petersburg to start up a mechanical workshop. The business goes bankrupt in 1856.



1850
After being reunited with his father in Russia, Nobel travels to France. In Paris he is employed in the laboratory of chemist TJ Pelouze.

1862
In a quest to develop new products for his father's shop, Nobel embarks on the research into nitroglycerin that will lead to dynamite.

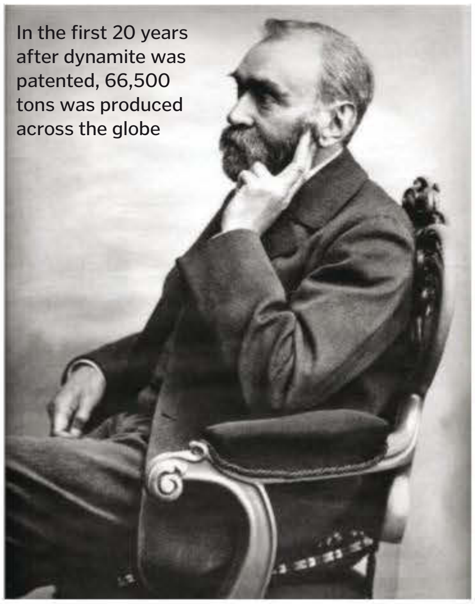


DID YOU KNOW? *As a child, Alfred became fluent in English, French, German and Russian, as well as his native Swedish*

Nobel was also interested in other aspects of chemistry, including the manufacture of synthetic rubber, leather, artificial silk and more

wealthy man at the heart of a brand-new industry. He established some 16 factories for producing explosives in almost as many countries.

Nobel died aged 63 at his home in San Remo, Italy. Without the help of a lawyer, a year before his death Nobel had signed his last will and testament. In it he passed much of his wealth to the establishment of an annual prize that he hoped would stimulate scientific progress. He wrote: 'The whole of my remaining realisable estate shall be dealt with in the following way: the capital, invested in safe securities by my executors, shall constitute a fund, the interest on which shall be annually distributed in the form of prizes to those who, during the preceding year, shall have conferred the greatest benefit on mankind.'


In the first 20 years after dynamite was patented, 66,500 tons was produced across the globe

In their footsteps...

Ragnar Sohlman

Swedish chemical engineer Ragnar Sohlman became Nobel's personal assistant when he moved to San Remo in 1883. Together with civil engineer Rudolf Lilljequist, Sohlman was appointed executor of Nobel's will. He fought both family and awarding bodies contesting the will to ensure the Nobel prize was set up. Sohlman was also creator of the Nobel Foundation and became its executive director from 1929-1946.

Albert Einstein

Without a doubt one of the most renowned Nobel laureates since the award was set up is Albert Einstein, who received the Nobel Prize in Physics in 1921. In 1905 he had published four pioneering papers: on the photoelectric effect, Brownian motion, the special theory of relativity and equivalence of matter and energy ($E=mc^2$). Einstein famously commented on the irony that a man credited with developing devastating explosives used to wage war had created a prize for peace.

1863
Nobel patents nitroglycerin (a volatile blasting oil) for use as an industrial explosive as well as a blasting cap detonator to set off explosions.

1864
Nobel's brother Emil dies while carrying out nitroglycerin experiments.

1866
Keen to make handling nitroglycerin safer, Nobel finds the oil can be stabilised by adding diatomaceous earth – and dynamite is born.

1871
After being granted a patent for dynamite in 1867, Nobel sets up the British Dynamite Company (later renamed Nobel's Explosives Company).

1895
Nobel's last will is signed at the Swedish-Norwegian Club in Paris.

1896
Nobel dies at home in San Remo, Italy, on 10 December.

© Alamy; Corbis; Adam Redzikowski

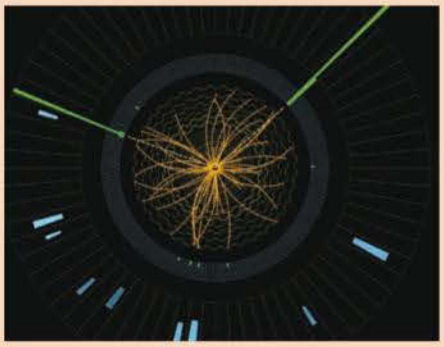
Peter Higgs

Well known in the scientific community for decades, it's only with the suspected discovery of the Higgs boson in 2012 that this physicist shot into the limelight

We can safely say that the 4 July 2012 discovery of a new particle, likely to be the elusive Higgs boson, had to be the biggest scientific announcement of that year. For most, it was enough to know that the Large Hadron Collider (LHC) – that huge, super-expensive particle accelerator in Switzerland – had given real weight to some decades-old but cohesive physical theory. Some impressive figures were released, then impossible speeds and inconceivably small theoretical particles existing for infinitely short expanses of time were mentioned, and our collective imaginations were captured. For its namesake Peter Higgs though, it must have felt like the ultimate validation of his entire lifelong career.

The big idea

The existence of the Higgs boson hasn't been proven absolutely, but CERN's experiments did confirm the existence of a new particle that is consistent with Higgs' theory. For most physicists, there's no doubt it's the Higgs boson. What this particle proves is the existence of the Higgs field, which allows the building blocks of our universe to gain mass and form stars, planets, galaxies and everything around us. Currently, it provides the answers to the last few burning questions in the Standard Model of Physics, and in the future it could prove integral to science.

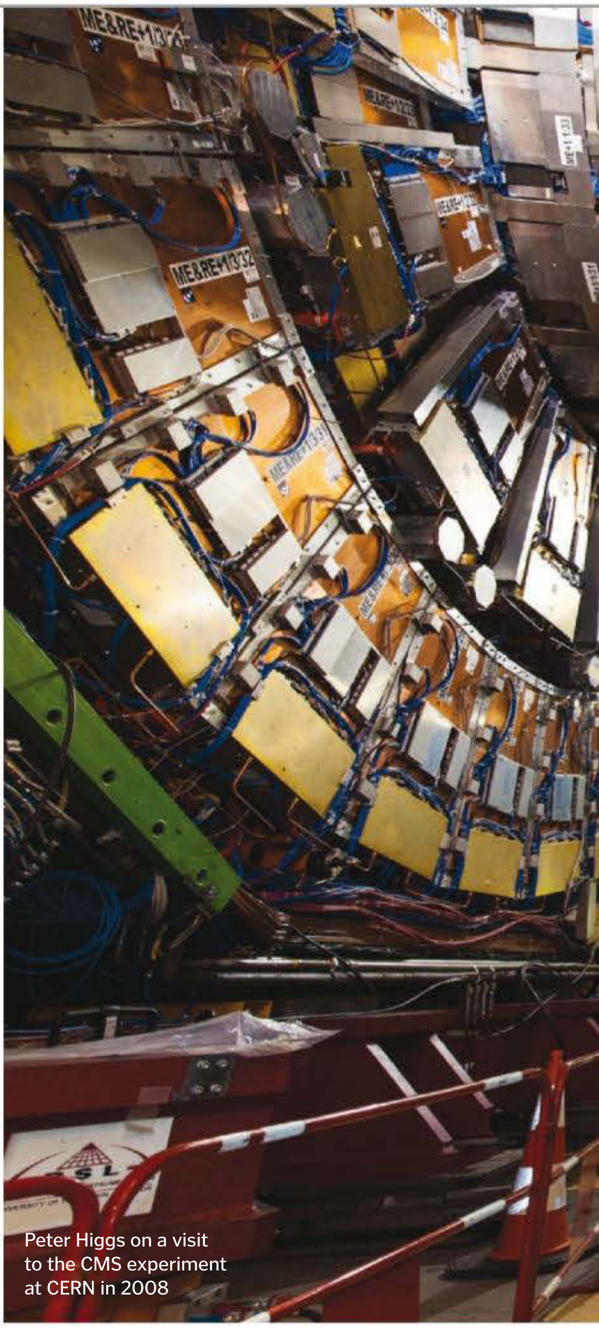


Higgs was born in Newcastle-upon-Tyne, UK, in 1929. He graduated from King's College in the University of London with a first-class degree in Physics then went on to secure a Master's and finally a doctorate in 1954. It was during his work as a research fellow and a lecturer that Higgs began the basis of a paper that would help describe the very nature of mass, even if it was completely disregarded at first. Higgs' work began in quantum field theory – the surreal world of the forces that bind subatomic particles and an exciting new area at the time.

His first paper on the Goldstone boson was picked up and published by a physics journal edited at the only recently founded CERN in Switzerland that same year. To his dismay though, his next paper – finished in 1964 – was rejected on the basis that it bore no relevance to physics. This paper described the radical concept of what became known as the Higgs mechanism, a scalar field present in all points of space, which gives particles mass. The Higgs mechanism was independently discovered by several other leading physicists in the same year, however none of them made any mention of a massive boson, which Higgs had gone on to include in a revision of the same paper.

Higgs' ideas were used to describe the origins of particle mass by physicists Steven Weinberg and Abdus Salam in the late-Sixties – a solution to which had eluded the scientific community for some time.

By 1983 – the same year that Peter Higgs became a fellow of the Royal Society – the only unproven parts of this electroweak theory were the Higgs field and the Higgs boson, but it took him nearly 20 years and physical experiments of an unprecedented scale in the LHC and beyond, to finally draw a line under the Higgs boson.



Peter Higgs on a visit to the CMS experiment at CERN in 2008

Peter Higgs retired in 1996 from a career that also saw him win the Rutherford Medal and the Dirac Medal. In the wake of 2012's CERN announcement, he has received praise from many notable peers – including Stephen Hawking, who has publicly recommended him for the Nobel Prize in Physics.

A life's work

The big events that led to the discovery of this tiny particle

1929
Born on 29 May, the family moves around a lot as Higgs' father is a sound engineer for the BBC.

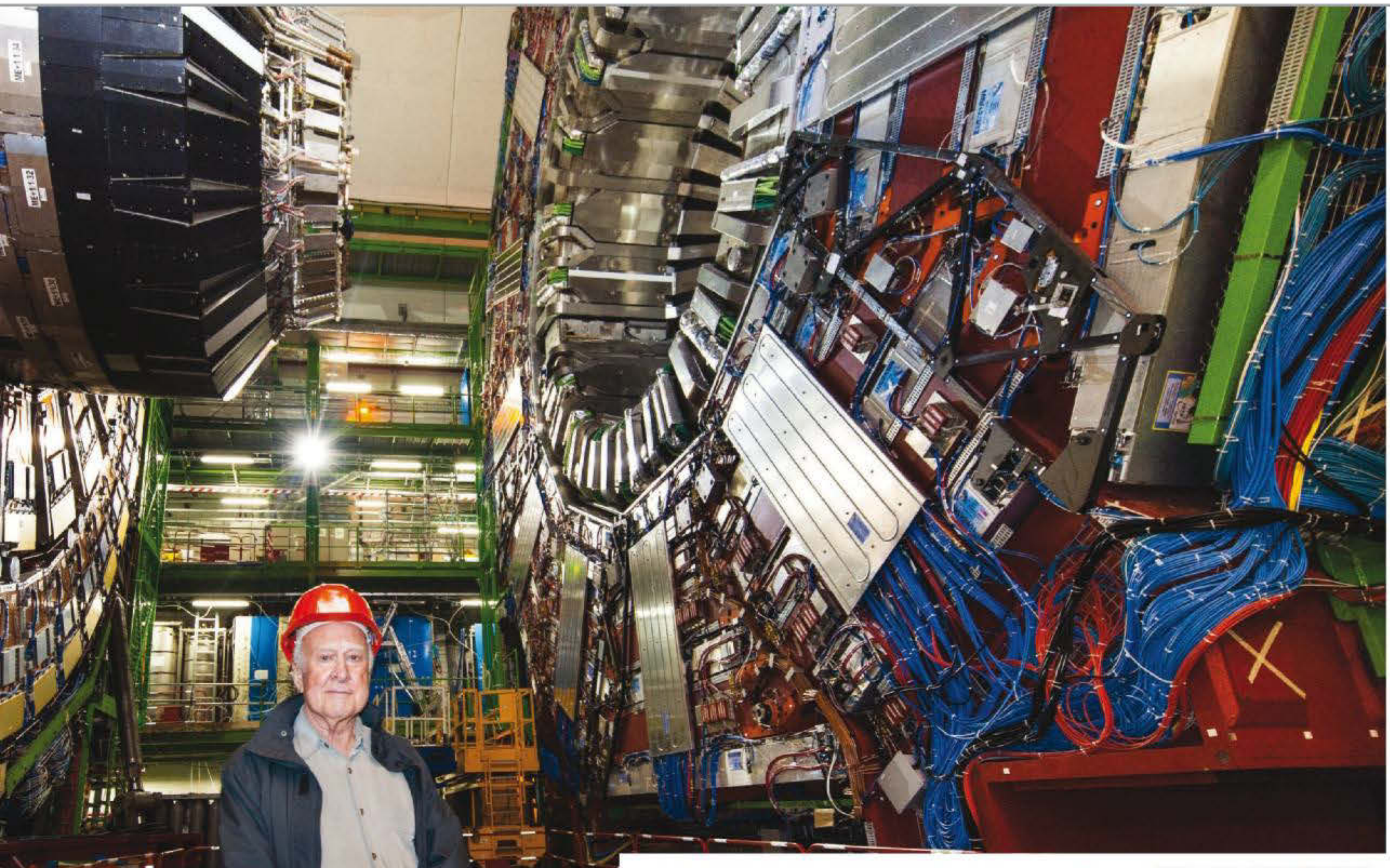
1954
Finishes his PhD at King's College London (right) and goes on to lecture at the University of Edinburgh.

1964
He describes the Higgs mechanism in a paper, which is rejected. He later revises it to include the Higgs boson.

1983
W and Z bosons are discovered, leaving only the Higgs particle to confirm the electroweak theory. Higgs also enters the Royal Society.

1991
Higgs becomes a fellow at the prestigious Institute of Physics, London.

DID YOU KNOW? *Reacting to the discovery, Higgs said "It's very nice to be right sometimes"*



Without the £6.2b ($9b) LHC at CERN the Higgs boson would remain only theory

In their footsteps…

Ken Currie

The celebrated Scottish artist Ken Currie was commissioned by the University of Edinburgh to paint a portrait of Peter Higgs in 2008. He admitted to being inspired by Higgs' work – not claiming to understand his theory, per se, but grasping the sublime and 'beautiful' nature of his solution.

Sir David Wallace

Higgs was Wallace's advisor while he was studying a PhD in elementary particle theory. Formerly a researcher at Princeton University and a lecturer at Southampton University, it's for his work as director of the Edinburgh Parallel Computing Centre that he was awarded a CBE.

> *"During his work as a lecturer Higgs began the basis of a paper that would help describe the very nature of mass"*

1996
Higgs retires and becomes emeritus professor at the University of Edinburgh.

1997
He receives an award for his work in theoretical physics, named after a hero of his: theoretical physicist Paul Dirac (right).

2004
Another award – this time the Israeli Wolf Prize in Physics, though Higgs refuses to fly to Jerusalem to receive it on moral grounds.

2011
The results of CERN's initial experiments with the LHC in December are extremely positive, but more tests are needed to be certain.

2012
The strongest indication of a new particle with significant mass is announced by CERN in July. For his work, Higgs is made a Companion of Honour at the start of 2013.

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Charles Darwin

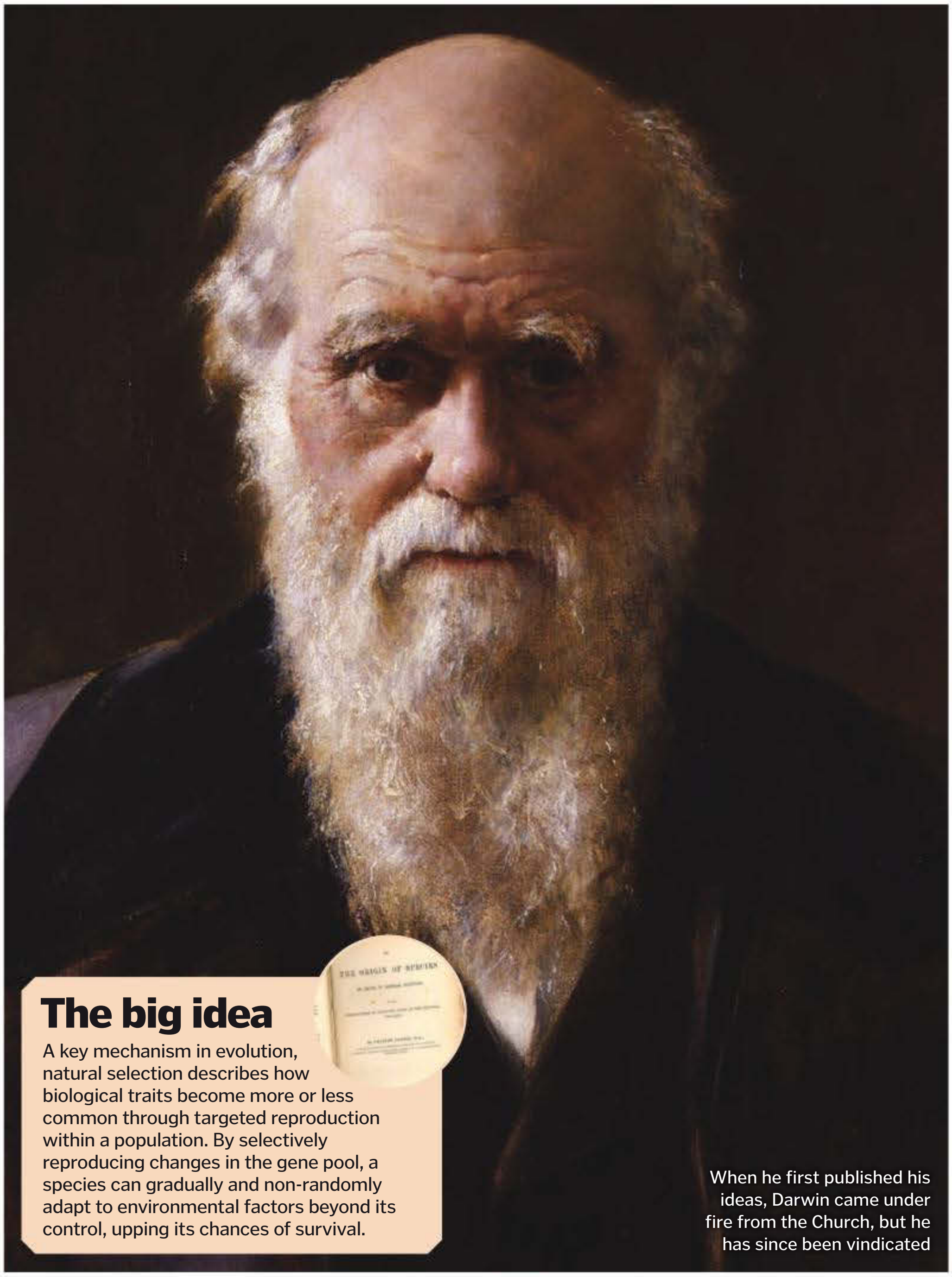
The father of evolutionary biology, Darwin is the most famous naturalist of the Victorian era, if not all time

Charles Robert Darwin was an English naturalist renowned today for his theories of evolution and natural selection, both of which were introduced in his seminal work *On The Origin Of Species*. The book was both lambasted and celebrated on its publication. Early controversy stemmed from its apparent undermining of religious scripture, but it would become one of the most influential works of Western society, with the entire field of evolutionary studies arising from it.

Though *On The Origin Of Species* was published in 1859, Darwin originally conceived of evolution by natural selection shortly after an around-the-world tour starting in 1831. He embarked on the journey to expand his newly formed interest in natural history, spending the trip collecting specimens and analysing many interesting species, when not suffering from seasickness. During the expedition on HMS Beagle he collected over 5,436 skins, bones and carcasses of various creatures. His experiences and findings led him to question many of the accepted beliefs at the time concerning life's origins.

In 1838 he pinned down his theory of natural selection proper – see 'The big idea' boxout for more details. Over the next 20 years, he continued to refine it until he received a letter from fellow British naturalist Alfred Russel Wallace proposing a collaboration. The fact that both men shared the same ideas led to the joint publication of their research. While Wallace's hypotheses on the subject were detailed, his hands-on research was lacking and Darwin's extensive fieldwork won out, with history since attributing the theory largely to the latter.

The publication of *On The Origin Of Species* the following year was therefore a landmark moment for Darwin – and for science as a



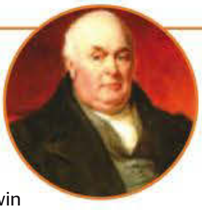
When he first published his ideas, Darwin came under fire from the Church, but he has since been vindicated

The big idea

A key mechanism in evolution, natural selection describes how biological traits become more or less common through targeted reproduction within a population. By selectively reproducing changes in the gene pool, a species can gradually and non-randomly adapt to environmental factors beyond its control, upping its chances of survival.

A life's work

Famous for describing the evolution of humanity, we chart Darwin's own evolution through the 19th century



1809
Charles Darwin is born in Shrewsbury, England. His parents are Robert (above) and Susannah Darwin.

1818
In June, Darwin goes to Shrewsbury School as a boarder, where he studies for seven years.

1825
Darwin signs up for medical courses at the University of Edinburgh with elder brother Erasmus.

1827
He is admitted to Christ's College Cambridge to study not science but divinity.

1831
Accepts an offer to join a voyage on HMS Beagle which sets sail on 27 December.

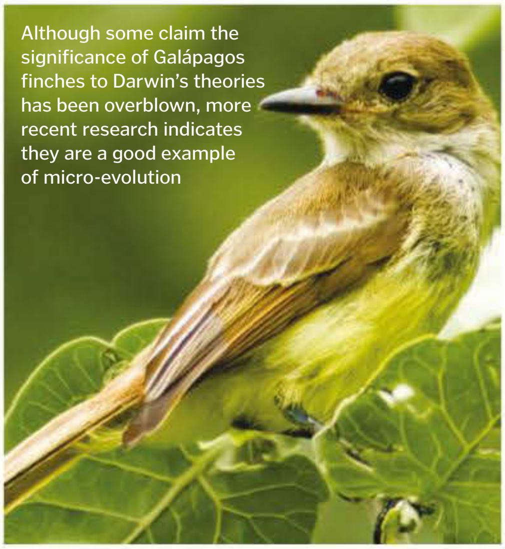
DID YOU KNOW? *From a young age Darwin collected and performed experiments on stones and beetles with his brother*

The HMS Beagle spent just five weeks in the Galápagos Islands, but that was long enough for Darwin's research purposes

whole. To a degree it was a bringing together of various ideas that had already been mooted by other biologists but unproved. While Darwin did not supply concrete evidence for evolution, the work's lucidity and logic meant that, towards the end of the 1870s, the scientific community, and society as a whole, had accepted his views.

Darwin followed up this groundbreaking title in 1871 with *The Descent Of Man, And Selection In Relation To Sex*, where he applied his own evolutionary theory specifically to human's evolution from apes. This book was incredibly popular from the word go, with a reprint ordered within just three weeks of publication. Three months after its release, 4,500 copies had been sold – a testament to his rising fame.

Darwin died on 19 April 1882 from heart disease and, after a request by his colleagues, was granted a state funeral at Westminster Abbey, buried alongside other famous scientists John Herschel and Isaac Newton.


Although some claim the significance of Galápagos finches to Darwin's theories has been overblown, more recent research indicates they are a good example of micro-evolution

Perhaps the most famous resident of the Galápagos, the giant tortoise

Five facts: Charles Darwin

1 Family guy
Darwin had ten children, though two died while still young. Three of his sons went on to become members of the Royal Society themselves.

2 On the money
Darwin is commemorated in the UK with his portrait printed on £10 banknotes, alongside a hummingbird and the ship HMS Beagle.

3 School of thought
The school that Charles Darwin attended as a boy, Shrewsbury School, still exists, but it is no longer in the same building, which has since become a library.

4 Name gets around
Due to Darwin's great achievements in the field of natural history, more than 120 species and nine different genera have been named in his honour to date.

5 No sea-lover
HMS Beagle took five years to circumnavigate the globe, but Darwin only spent 18 months on board. From the day it set sail, he was afflicted with terrible seasickness.

> *"The publication of* On The Origin Of Species *was a landmark moment for Darwin – and for science"*

1836
Lands back in England on 2 October and returns home to Shrewsbury.

1839
Marries Emma Wedgwood and has his first of ten children.

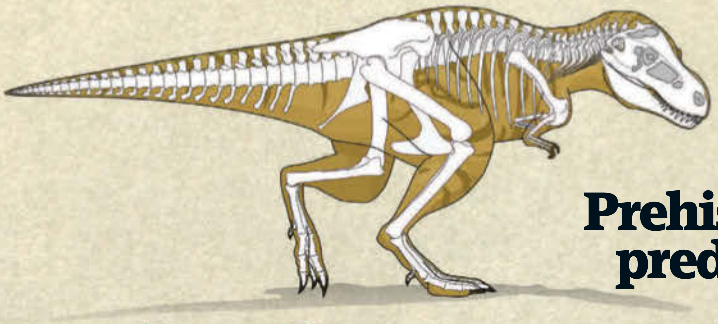
1858
Receives a letter from Alfred Russel Wallace who shares many of his ideas about the theory of natural selection.

1859
Publishes *On The Origin Of Species By Means Of Natural Selection, Or The Preservation Of Favoured Races In The Struggle For Life.*

1864
Receives the Copley Medal, the highest accolade from Britain's Royal Society.

1882
Darwin dies, aged 73, and is buried at Westminster.

© Mike Cornwell



162

Prehistoric predators

PREHISTORIC

150 **101 gigantic facts about dinosaurs**
Get to know amazing facts about these prehistoric beasts

162 **Prehistoric predators**
Take a closer look at some of the largest carnivores the world has ever seen

166 **Biggest ever land mammal**
Find out about the prehistoric mega-mammal, Paraceratherium

168 **Velociraptors**
Despite its small size, this scavenger was one of the deadliest dinosaurs

170 **Meet the real Brontosaurus**
Discover one of the largest animals to ever grace the Earth

172 **Ankylosaurus**
Learn all about the club-wielding giant

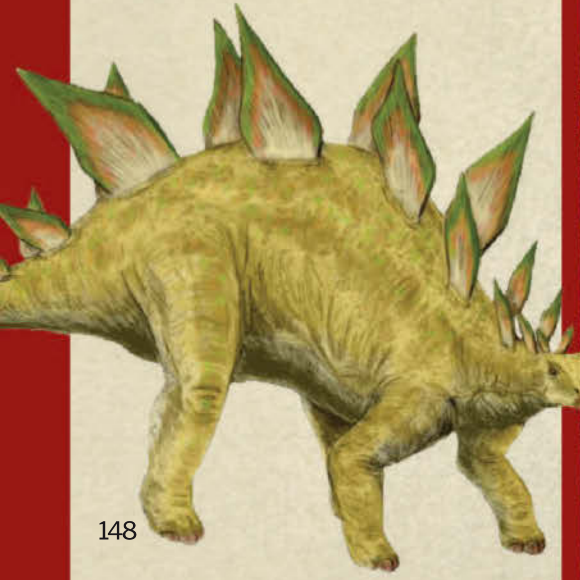
174 **Sabre-toothed cats**
Learn how the biggest of the big cats lived and died on the American plains

101 gigantic dinosaur facts

150

152

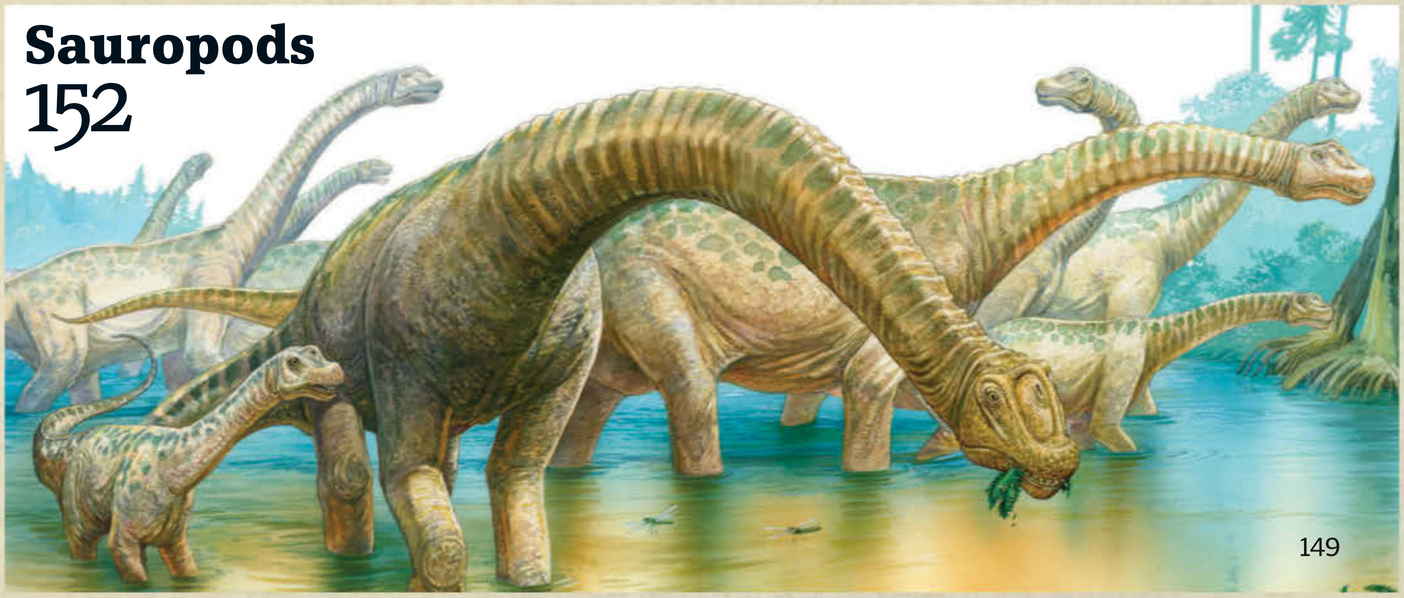
Sauropod species



Sabre-toothed cats 174

164 Dinosaur scale

168 Velociraptors



Sauropods 152

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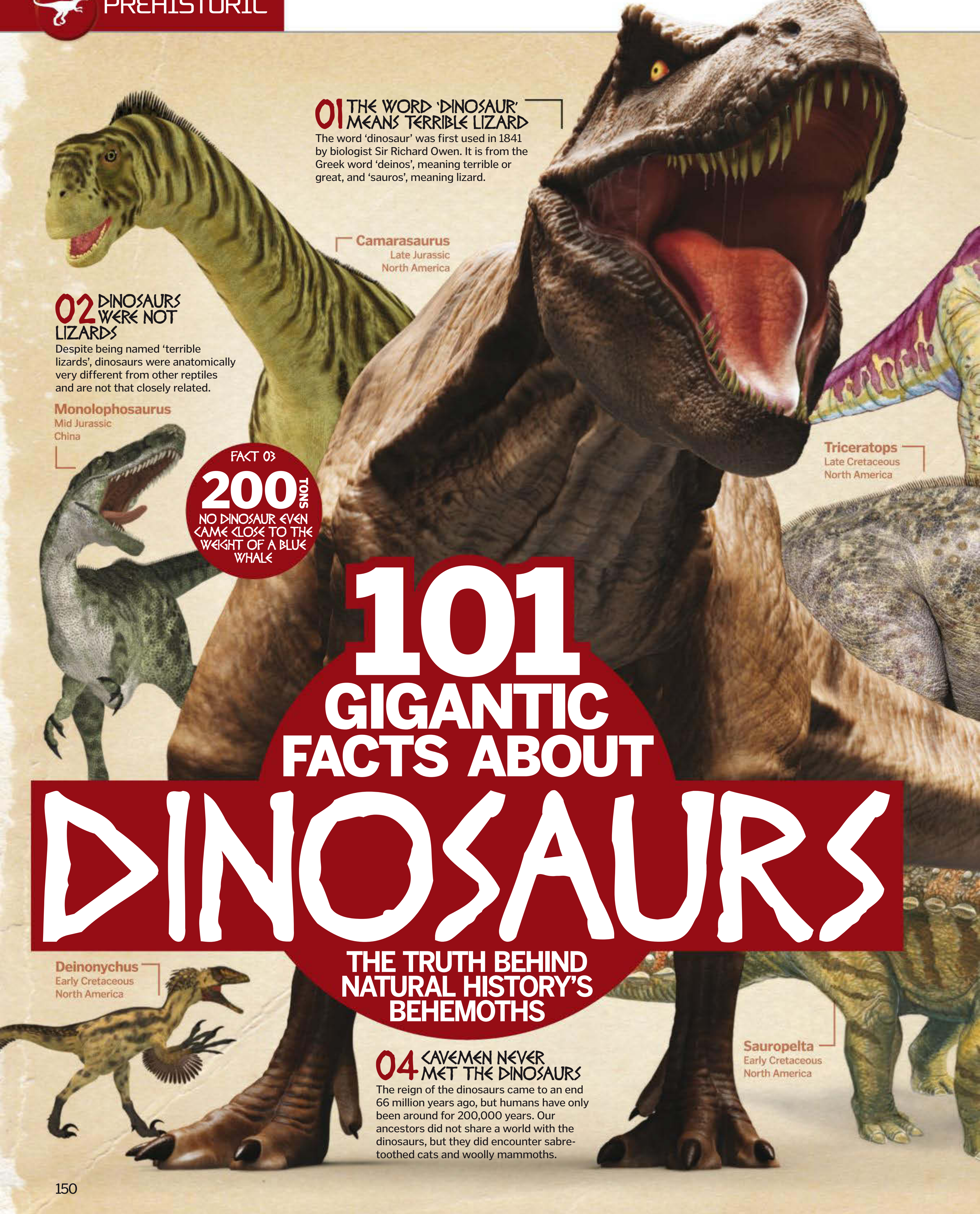
101 GIGANTIC FACTS ABOUT DINOSAURS

THE TRUTH BEHIND NATURAL HISTORY'S BEHEMOTHS


Camarasaurus
Late Jurassic
North America
Monolophosaurus
Mid Jurassic
China
Triceratops
Late Cretaceous
North America
Deinonychus
Early Cretaceous
North America
Sauropelta
Early Cretaceous
North America

01 THE WORD 'DINOSAUR' MEANS TERRIBLE LIZARD

The word 'dinosaur' was first used in 1841 by biologist Sir Richard Owen. It is from the Greek word 'deinos', meaning terrible or great, and 'sauros', meaning lizard.

02 DINOSAURS WERE NOT LIZARDS

Despite being named 'terrible lizards', dinosaurs were anatomically very different from other reptiles and are not that closely related.

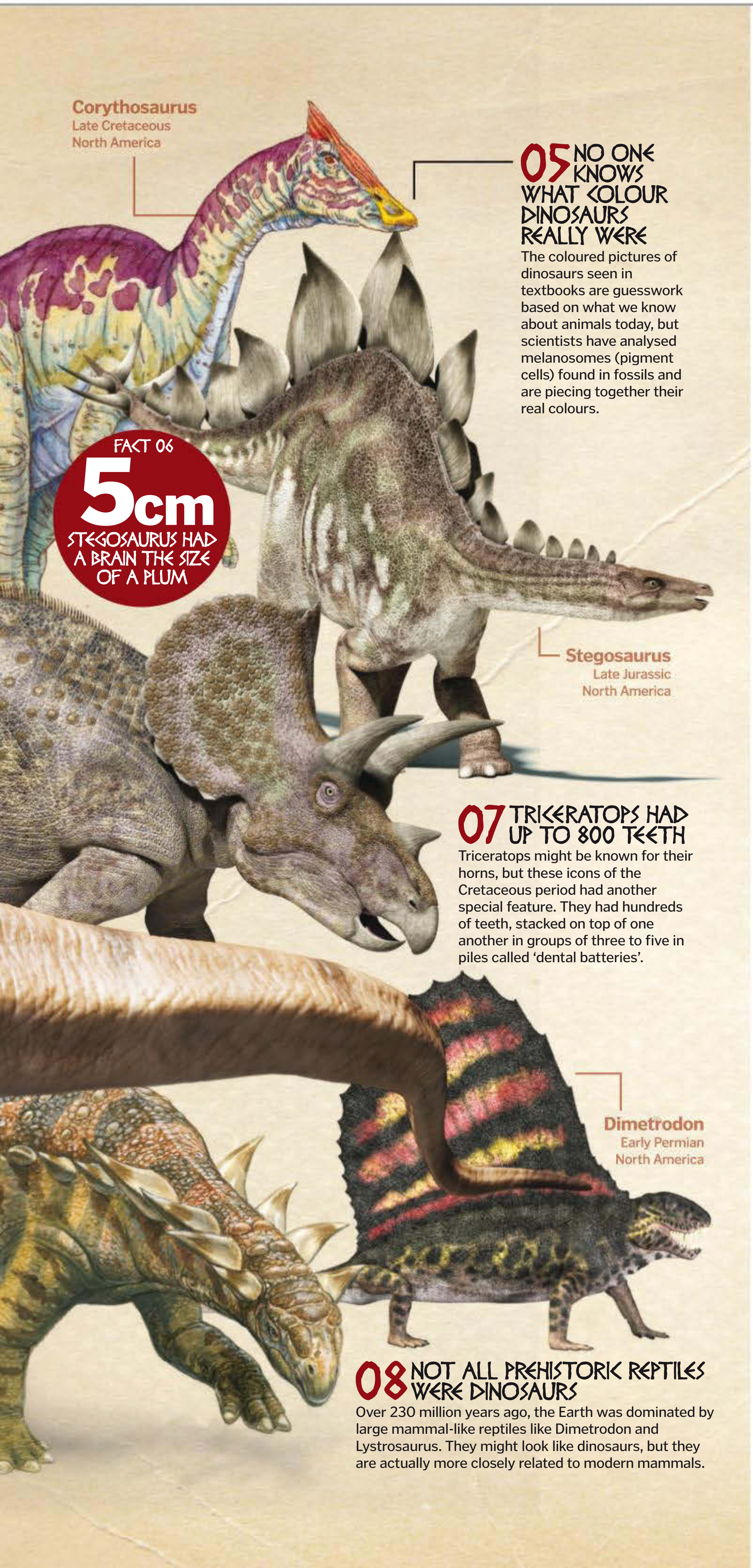
FACT 03

200 TONS

NO DINOSAUR EVEN CAME CLOSE TO THE WEIGHT OF A BLUE WHALE

04 CAVEMEN NEVER MET THE DINOSAURS

The reign of the dinosaurs came to an end 66 million years ago, but humans have only been around for 200,000 years. Our ancestors did not share a world with the dinosaurs, but they did encounter sabre-toothed cats and woolly mammoths.



05 NO ONE KNOWS WHAT COLOUR DINOSAURS REALLY WERE

The coloured pictures of dinosaurs seen in textbooks are guesswork based on what we know about animals today, but scientists have analysed melanosomes (pigment cells) found in fossils and are piecing together their real colours.

FACT 06

5cm

STEGOSAURUS HAD A BRAIN THE SIZE OF A PLUM

07 TRICERATOPS HAD UP TO 800 TEETH

Triceratops might be known for their horns, but these icons of the Cretaceous period had another special feature. They had hundreds of teeth, stacked on top of one another in groups of three to five in piles called 'dental batteries'.

08 NOT ALL PREHISTORIC REPTILES WERE DINOSAURS

Over 230 million years ago, the Earth was dominated by large mammal-like reptiles like Dimetrodon and Lystrosaurus. They might look like dinosaurs, but they are actually more closely related to modern mammals.

A BRIEF HISTORY OF DINOSAURS

Around 230 million years ago, the world was a very different place. The land was joined together to form a single continent, and the dominant animals were reptiles. These enormous animals included some of the largest and most fearsome creatures to have ever walked the Earth.

Over the course of their 165-million-year reign, the world underwent some truly tremendous changes. The landmasses tore apart, and the climate became cooler and wetter. Seas appeared and disappeared, and plants started to dominate the land, covering the landscape in ferns, horsetails and conifers.

Over the course of the Mesozoic Era, dinosaurs came to inhabit every landmass, diversifying into a huge variety of weird and wonderful shapes. All dinosaurs are thought to be descended from a small two-legged ancestor weighing just a few kilograms, but some evolved claws for grasping, others had bony armour, spikes, scales and horns, and some became enormous four-legged giants with extremely long necks and tails. Over time, dinosaurs became larger and larger on average.

These enormous animals were reliant on the environment for their survival, but 66 million years ago disaster struck. Around this time, a colossal asteroid struck the Earth, volcanic eruptions spewed ash into the sky, and high oxygen levels fuelled fires on the ground. The sea level dropped and 75 per cent of life on the planet perished as a result.

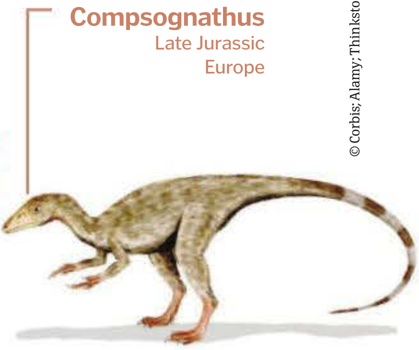
Mammals could keep warm, were able to reproduce more rapidly and could burrow underground, so they quickly came to dominate the post-dinosaur world. Although the large dinosaur species died out in the mass extinction event, some of the theropods survived. They had evolved to become smaller over time, so were better able to cope with the changing environment. There is mounting evidence that birds descended from these adaptable dinosaurs.

The dinosaurs are some of the most successful animals to have ever lived on Earth. They dominated the planet for over 150 million years, and despite suffering catastrophic losses at the time of the mass extinction event 66 million years ago, their ancestors are still among us and still manage to colonise every corner of the planet.

FACT 09

3.5KG

COMPSOGNATHUS, ONE OF THE SMALLEST DINOS, WAS ONLY JUST LARGER THAN A CHICKEN



© Corbis; Alamy; Thinkstock

SAUROPODS

These long-necked giants are among the largest animals to have ever lived

10 SAUROPODS WERE HUGE HERBIVORES

The four-legged dinosaurs with long tails and necks are known as sauropods. The most common were Diplodocus and Camarasaurus.

11 DIPLODOCUS HAD 15 VERTEBRAE IN ITS NECK

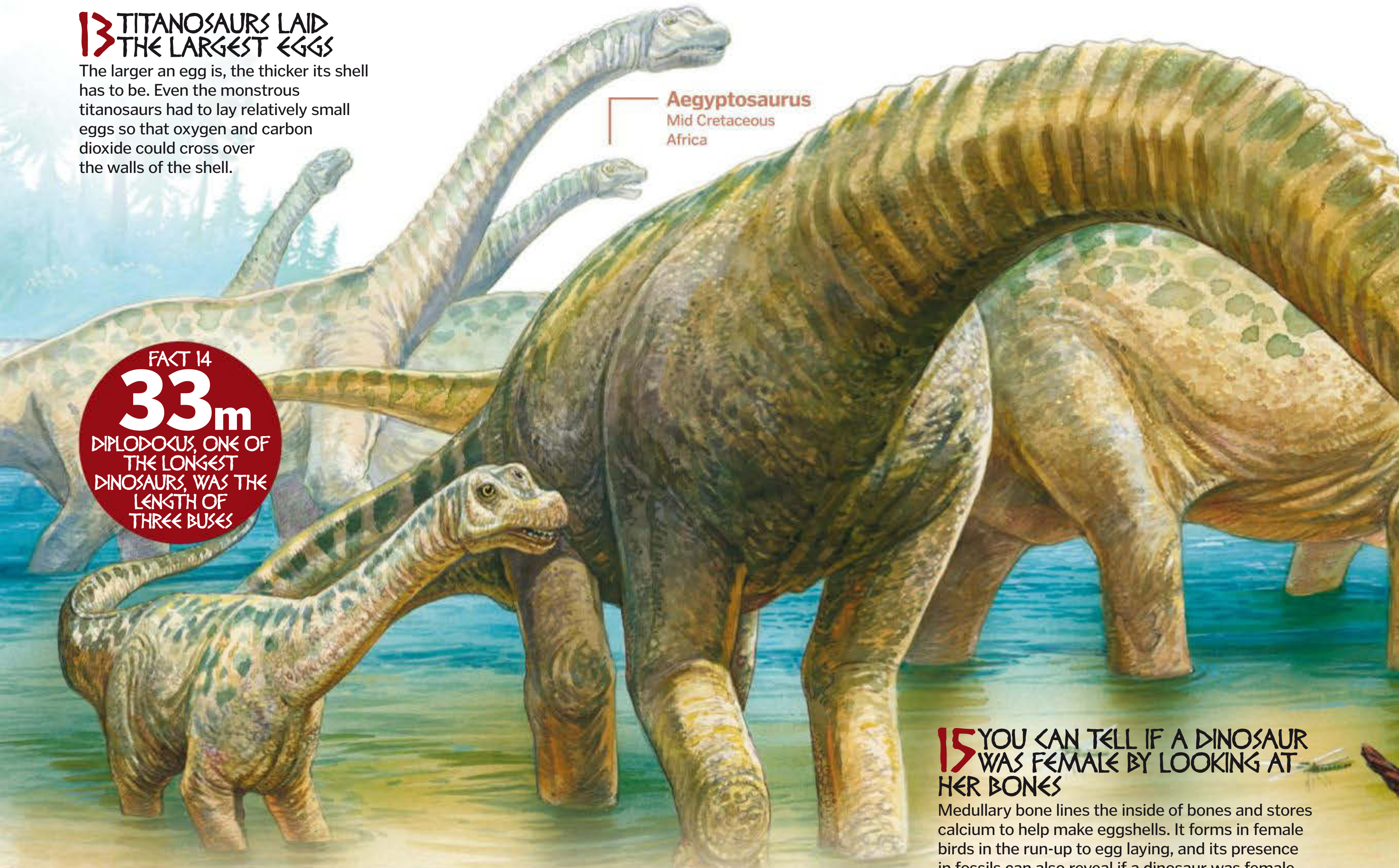
At least, we think it did – there are very few complete specimens. For comparison, a human has seven neck vertebrae.

12 SAUROPODS DID NOT LIVE IN WATER

Early ideas about how sauropods like Diplodocus lived portrayed them walking underwater like hippos. They had nostrils on the top of their heads, and scientists thought they would use their necks like snorkels. However, with large bodies, the crushing weight of water would have prevented them from breathing, and we now know they lived on land.

13 TITANOSAURS LAID THE LARGEST EGGS

The larger an egg is, the thicker its shell has to be. Even the monstrous titanosaurs had to lay relatively small eggs so that oxygen and carbon dioxide could cross over the walls of the shell.

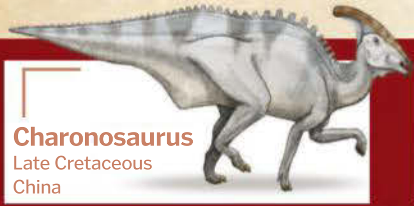


Aegyptosaurus
Mid Cretaceous
Africa

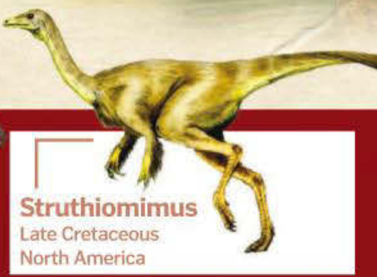
FACT 14
33m
DIPLODOCUS, ONE OF THE LONGEST DINOSAURS, WAS THE LENGTH OF THREE BUSES

15 YOU CAN TELL IF A DINOSAUR WAS FEMALE BY LOOKING AT HER BONES

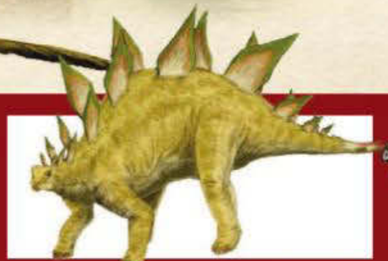
Medullary bone lines the inside of bones and stores calcium to help make eggshells. It forms in female birds in the run-up to egg laying, and its presence in fossils can also reveal if a dinosaur was female.

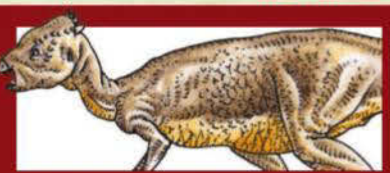


Charonosaurus
Late Cretaceous
China



Struthiomimus
Late Cretaceous
North America





Pachycephalosaurus
Late Cretaceous
North America

22 HADROSAURS HAD DUCK-LIKE BILLS

Hadrosaurs were the first dinosaurs found in North America, and since the 19th century, hundreds have been unearthed. These herbivores had a very distinctive appearance, with duck-like beaks adapted for clipping vegetation, and crested heads that might have been helped to transmit sounds over long distances.

23 ORNITHOMIMIDS LOOKED AND LIVED LIKE OSTRICHES

Ornithomimid means 'bird mimic', and these two-legged dinosaurs really do look familiar. They had long, muscular legs, large, rounded bodies and long necks with small heads. Like modern ostriches, these dinosaurs were extremely fast on their feet.

24 DINOSAURS DIDN'T HAVE TWO BRAINS

Stegosaurus had a tiny brain, but at the base of its spine there was an enlarged space. Scientists once thought it might have housed a second, larger brain to control its legs, but this idea has been discredited as birds have a similar opening to store the energy-rich substance glycogen.

25 PACHYCEPHALOSAURS HAD THICK SKULLS

Pachycephalosaur means 'thick-headed lizard'. The bone at the top of their skull could be up to 25cm (10in) thick, and their faces were covered in bumps and spikes. These dramatic features could have been for fighting, or they might just have been for show, like the antlers on modern deer.

DID YOU KNOW? The Cuban bee hummingbird is the smallest living descendant of the dinosaurs, measuring just 5cm (2in)

16 ANKYLOSAURUS WAS ONE OF THE LAST SURVIVING DINOSAURS

These heavily armoured dinosaurs had clubbed tails, weighed over 4,000kg (8,818lb) and were covered in bony plates. They were extremely tough, and no predator could tackle a full-grown adult.

17 HERDS OF DINOSAURS WERE FOSSILISED TOGETHER

At a bonebed in Alberta, Canada, at least 27 ceratopsids with frilled heads and horns were found buried together.

FACT 18

18.5m

SAUROPOSEIDON WAS ABOUT THREE TIMES TALLER THAN A GIRAFFE

19 PTEROSAURS WEREN'T DINOSAURS

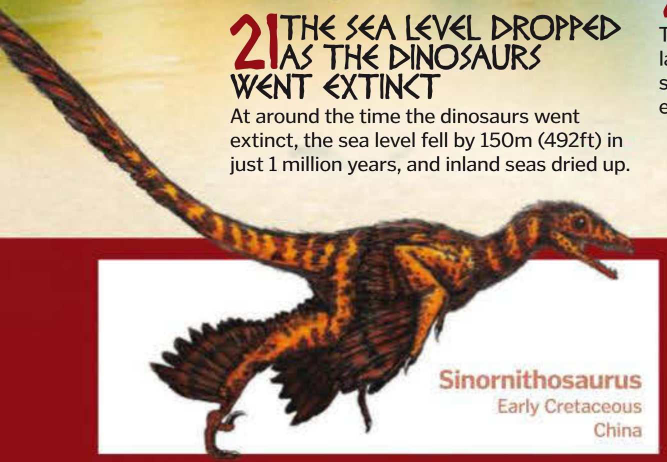
Pterodactyls are the iconic flying dinosaurs, but they weren't actually dinosaurs at all. Dinosaurs were all land animals. Quetzalcoatlus, the largest pterosaur of all, had a 12m (39ft) wingspan, making it the largest animal that ever flew.

20 BIG BODIES KEPT DINOSAURS WARM

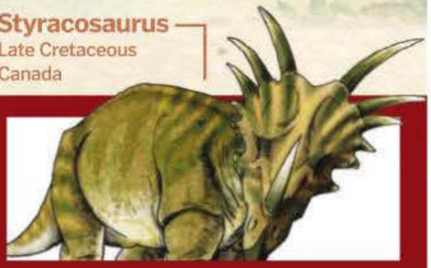
This process is known as 'thermal inertia'. The larger the body of an animal, the lower the surface-to-volume ratio – preventing heat escaping from the skin.

21 THE SEA LEVEL DROPPED AS THE DINOSAURS WENT EXTINCT

At around the time the dinosaurs went extinct, the sea level fell by 150m (492ft) in just 1 million years, and inland seas dried up.



Sinornithosaurus
Early Cretaceous
China



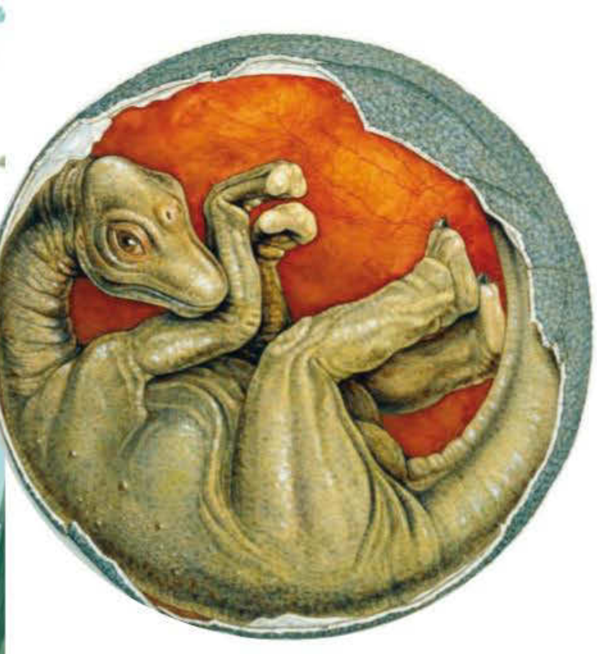
Styracosaurus
Late Cretaceous
Canada

26 DINOSAURS HAD FEATHERS

Despite what you might see in textbooks, museums and even in this article, we now know that most dinosaurs were not all scaly and bald. We have known for a while that the two-legged theropods had feathers, but in 2014 a very distantly related beaked dinosaur found in Siberia was also found to have feathers, suggesting scales were replaced early in dinosaur evolution.

27 CERATOPSIANS HAD HORNED FACES

The most famous ceratopsian is Triceratops, but there were other dinosaurs with horns and frills. These huge herbivores started to appear around 160 million years ago, and it is thought the frill was used as protection against predators, to impress potential mates and as a radiator to get rid of excess heat.



NESTS & EGGS

28 ALL DINOSAURS LAID EGGS

Dinosaurs all reproduced by laying eggs like modern-day birds, and some of the hatchlings were thousands of times smaller than the full-grown adults.

29 SOME DINOSAURS CARED FOR THEIR YOUNG

Adult Psittacosaurus have been found alongside the fossilised remains of their young, and the bones of older babies have been found in the nests of Maiasaura, indicating that they probably helped to raise their young.

30 THE LARGEST DINOSAUR EGG WAS OVER 60CM LONG

The largest dinosaur eggs were found in Mongolia in the 1990s, and measured around 45cm (17.7ft) across. Compared to the size of the adults, they are still surprisingly small.

31 SOME OF THE BEST DINOSAUR FOSSILS ARE BABIES

A 113-million-year-old fossilised baby dinosaur found in Italy still contains traces of preserved soft tissue, including intestines and tail muscles.

32 BABY DINOSAURS GREW RAPIDLY

Sauropods like Diplodocus weighed a tiny 5kg (11lb) at birth, and grew to 10,000 times their size within just 30 years. Fossilised embryos show sauropod bones filled with blood vessels, bringing nutrients to allow rapid growth.

33 THERE ARE TWO MAIN TYPES OF DINOSAUR EGG

Dinosaur eggs can be divided into two main categories – spheroidal and elongated. Rounder eggs were laid by herbivores such as sauropods, while elongated, bird-like eggs were laid by theropods.

34 OVIRAPTORS DIDN'T STEAL EGGS

The name 'Oviraptor' means egg thief, but these dinosaurs weren't criminals. They were actually devoted parents, and fossilised nests found in Mongolia show they arranged their eggs in spiral layers.

© Corbis; Thinkstock; Nobu Tamura; Michael B. H

TYRANNOSAURUS REX

35 YOU PROBABLY COULDN'T OUTRUN A TYRANNOSAURUS

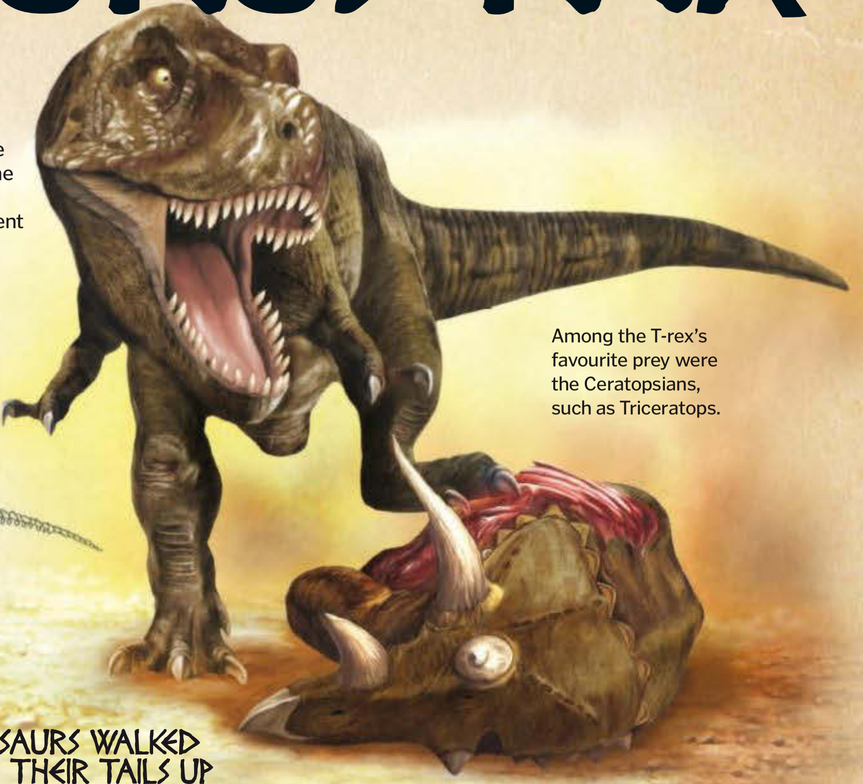
Computer simulations of T-rex running suggest that it had a top speed of around 29km/h (18mph). Not quite fast enough to catch up with a car, like in *Jurassic Park*, but quick enough to catch any human that's not an athlete.

36 THE LARGEST TYRANNOSAURUS FOSSIL IS CALLED SUE

Complete dinosaur fossils are incredibly rare, but there is one T-rex specimen that stands out from the rest. Sue is over 12.8m (40ft) long and stands over 3.9m (13ft) high. She is on display at the Chicago Field Museum and is the most complete specimen ever recovered.

37 STEGOSAURUS NEVER MET TYRANNOSAURUS

Despite being depicted together, these two would never have been in the same place at the same time. Stegosaurus lived during the Jurassic period and went extinct around 80 million years before T-rex first appeared at the end of the Cretaceous period.



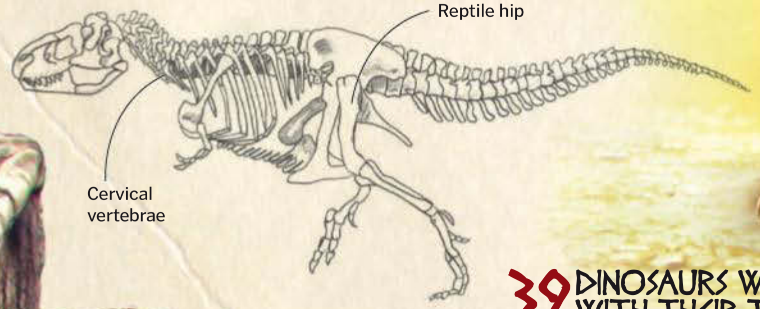
Among the T-rex's favourite prey were the Ceratopsians, such as Triceratops.

HEAD

It measured 1.5m (4.9ft) long, and had eye and nose cavities. The skull was of thick and heavy bone, although in some points it was pretty flexible.

38 SOME DINOSAURS HAD A WISHBONE

The 'V'-shaped wishbone you find in your Sunday roast is also present in meat-eating theropods such as T-rex.



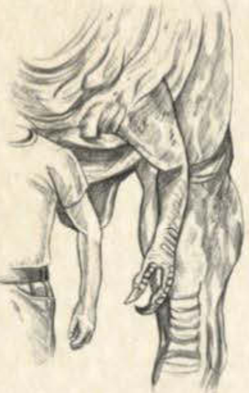
39 DINOSAURS WALKED WITH THEIR TAILS UP

Dinosaurs like T-rex had enormous heads, and used their tails as a counterweight, holding them up for balance.

40 THE MEAT-EATING DINOSAURS WERE ALL THEROPODS

T-rex, Allosaurus and Deinonychus belonged to a group of dinosaurs known as theropods. Some members of this group are the largest carnivores ever to have walked the Earth.

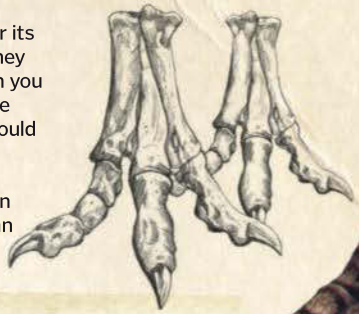
41 T-REX HAD TEETH THE SIZE OF BANANAS



The largest Tyrannosaurus rex teeth measured 30cm (12in) in length. There has been much debate as to what they were used for, but scientists generally agree that T-rex was both a hunter and a scavenger. Broken T-rex teeth found in the fossilised tailbones of Hadrosaurs indicate that hunts weren't always successful.

42 T-REX HAD STRONGER ARMS THAN A HUMAN

T-rex is often ridiculed for its stumpy little arms, but they were much stronger than you might imagine. They were used for grasping prey, could move rapidly and were capable of lifting around 200kg (440lb), more than three times as much as an adult man.



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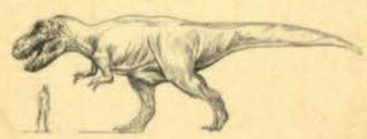


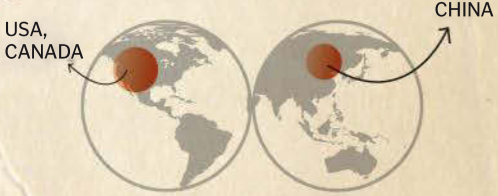
LENGTH 12.5m	CLASSIFICATION
WEIGHT 5,000kg	Theropoda;
DIET Carnivorous	Coelurosauria;
GENUS Tyrannosaurus	Tyrannosauroidea

43 THE MOST EXPENSIVE FOSSIL IS WORTH MORE THAN $8 MILLION

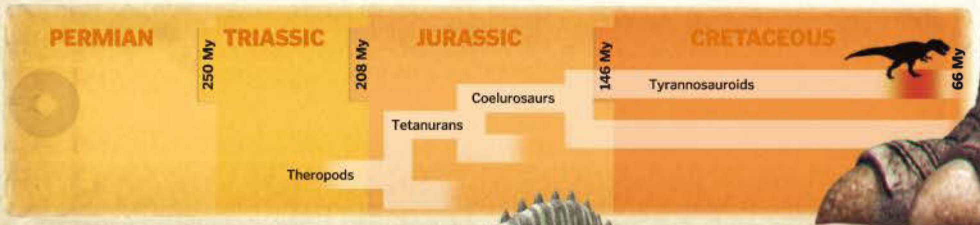
The famous Tyrannosaurus rex fossil known as Sue fetched $8.36 million at auction back in 1997 and is likely to be worth significantly more than that today.

FOUND IN…

The Tyrannosaurus rex was found in what is now North America, just like its cousins the Daspletosaurus, the Gorgosaurus and the Albertosaurus. The Tarbosaurus and the Guanlong, a primitive tyrannosaur of the Jurassic period, were discovered in Asia.



PHYLOGENETIC TREE

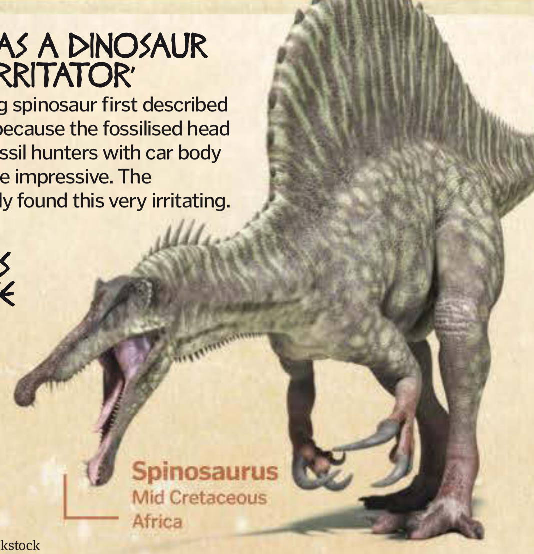


44 THERE WAS A DINOSAUR CALLED 'IRRITATOR'

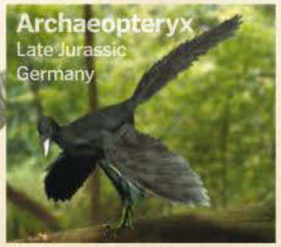
Irritator was a fish-eating spinosaur first described in 1996. It got its name because the fossilised head had been modified by fossil hunters with car body filler to make it look more impressive. The scientists understandably found this very irritating.

45 DINOSAURS DIDN'T LIVE IN THE SEA

Dinosaurs were land animals and were not closely related to the famous sea-dwelling Plesiosaur, but Spinosaurus was semi-aquatic and could run along the riverbed.



Spinosaurus
Mid Cretaceous
Africa



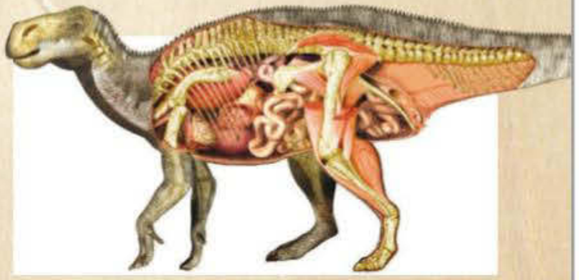
Archaeopteryx
Late Jurassic
Germany

46 NO DINOSAUR COULD FLY

Dinosaurs were all land-dwelling reptiles, and despite the fact that they are the ancestors of modern birds, none of them could fly.

47 ARCHAEOPTERYX IS THE FIRST FOSSIL EVIDENCE OF EVOLUTION

Archaeopteryx was the first feathered dinosaur to be discovered, linking birds and dinosaurs. The breakthrough came in 1861, just two years after Charles Darwin published his theory of evolution.



48 DINOSAURS WERE NEITHER WARM- NOR COLD-BLOODED

It was long thought that dinosaurs, like reptiles, were cold-blooded, but new evidence suggests they were mesothermic – able to burn energy to make some body heat, but not warm-blooded like mammals.

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CLASSIFICATION

Dinosaurs can be split into two major groups, with many more subdivisions

49 THE MEAT-EATING DINOSAURS WALKED ON TWO FEET

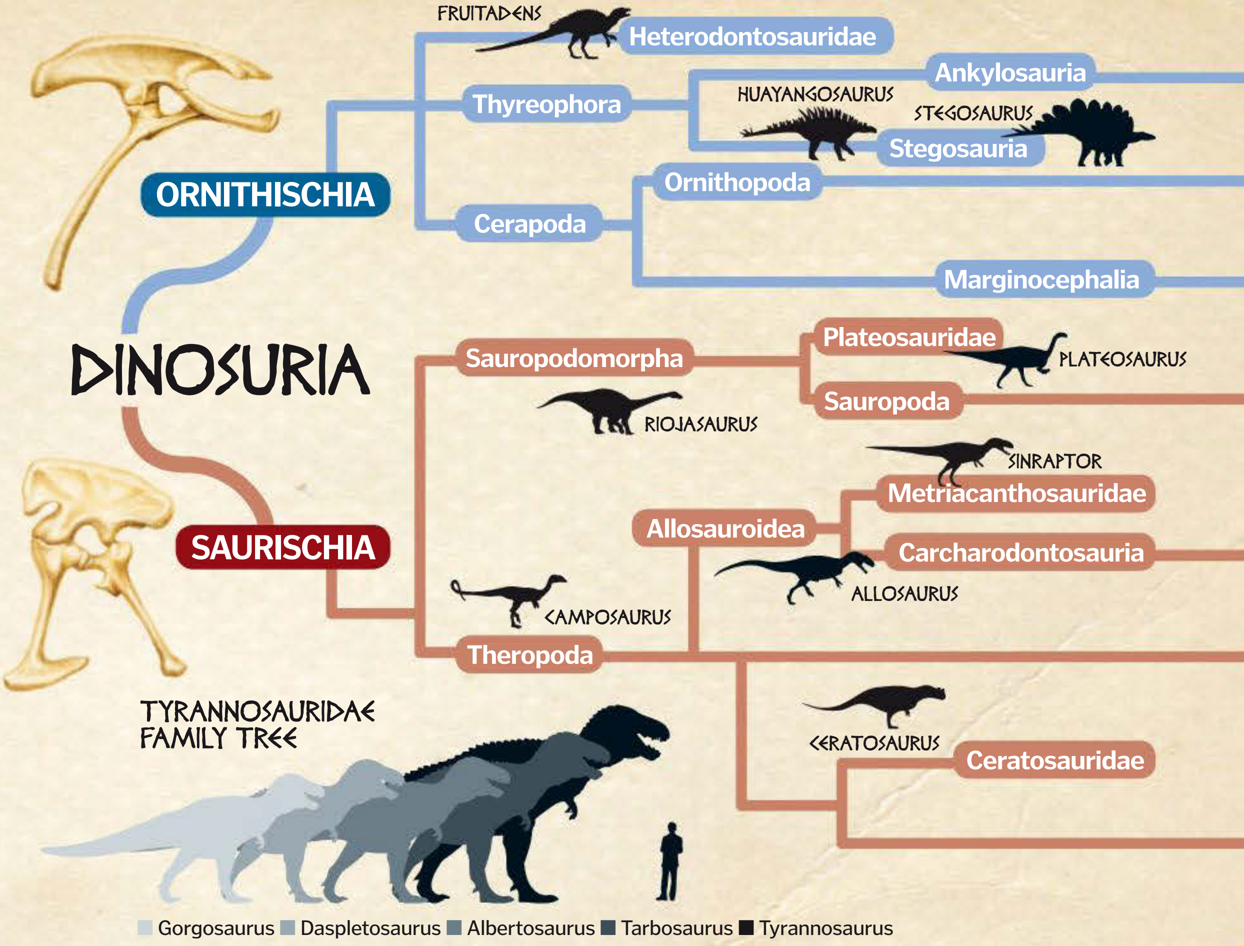
All the carnivorous dinosaurs were theropods (although not all theropods were carnivores) and walked upright on their two hind legs. They typically had hollow bones, three main fingers on each hand and foot, and sharp, curved teeth and claws used for hunting and eating.

50 DINOSAURS EITHER HAD LIZARD HIPS OR BIRD HIPS

Dinosaurs can be divided into two major groups based on their hipbones. The Ornithischia, or 'bird-hipped' dinosaurs had a pubic bone that pointed toward the tail, and the Saurischia, 'lizard-hipped' dinosaurs pointed toward the head. Interestingly, birds evolved from lizard-hipped dinosaurs.

51 MOST DINOSAURS ATE PLANTS

Dinosaurs are often portrayed as fearsome hunters, but the majority of species were herbivores. Even some of the ferocious-looking theropods actually ate plants and used their sharp claws for digging.


DINOSURIA
ORNITHISCHIA
FRUITADENS
Heterodontosauridae
Thyreophora
Ankylosauria
HUAYANGOSAURUS
STEGOSAURUS
Stegosauria
Cerapoda
Ornithopoda
Marginocephalia
SAURISCHIA
Sauropodomorpha
Plateosauridae
PLATEOSAURUS
Sauropoda
RIOJASAURUS
SINRAPTOR
Metriacanthosauridae
Allosauroidea
Carcharodontosauria
ALLOSAURUS
CAMPOSAURUS
Theropoda
CERATOSAURUS
Ceratosauridae
TYRANNOSAURIDAE FAMILY TREE
Gorgosaurus
Daspletosaurus
Albertosaurus
Tarbosaurus
Tyrannosaurus

56 DINOSAURS LIVED DURING THE MESOZOIC ERA

Dinosaurs ruled the Earth for 165 million years, in a time period known as the Mesozoic Era. This era can be split into three periods, Triassic, Jurassic and Cretaceous

57 DINOSAURS FIRST APPEARED 230 MILLION YEARS AGO

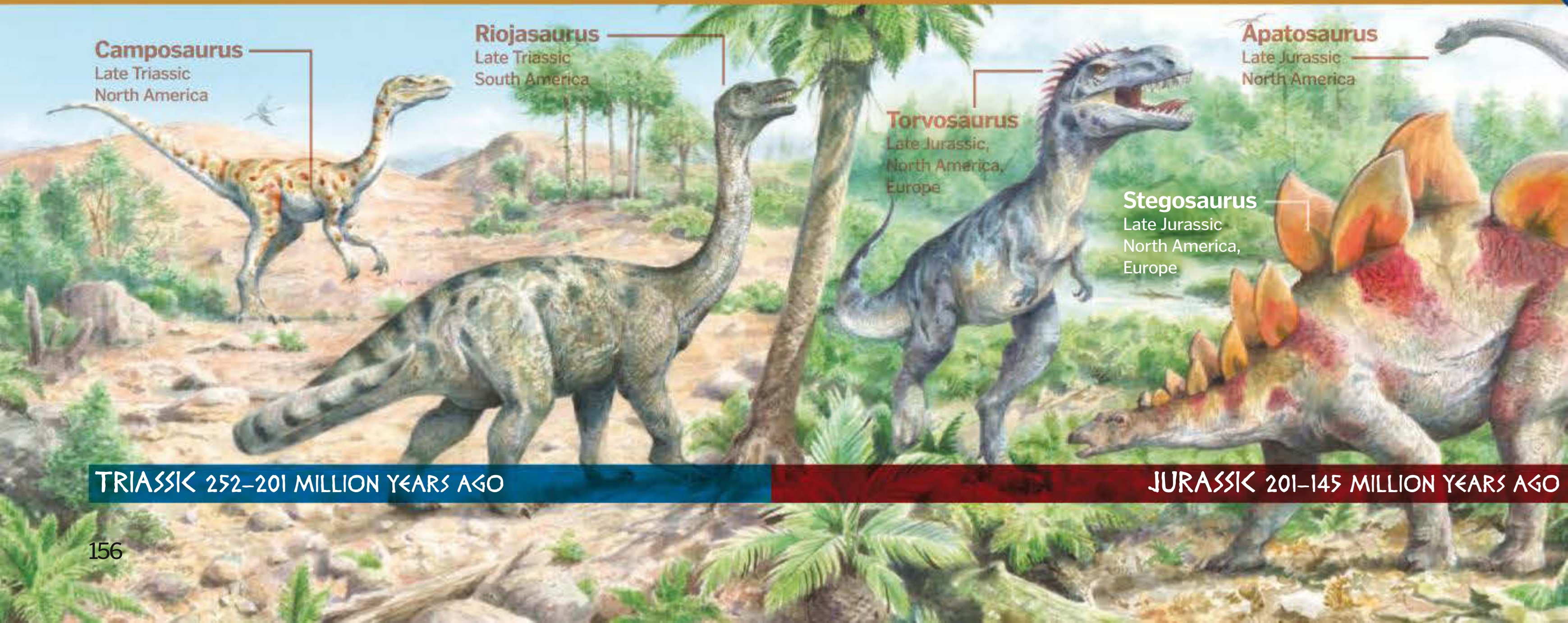
Dinosaurs evolved during the Triassic period, between 250 and 200 million years ago. The warm, dry conditions were perfect for breeding reptiles.

58 VOLCANIC ERUPTIONS CONTRIBUTED TO THE EXTINCTION OF THE DINOSAURS

Huge lava flows are present in the fossil record for about 500,000 years before the extinction of the dinosaurs, and many scientists think eruptions contributed to their extinction by filling the air with a thick cloud of ash.

59 EARLY DINOSAURS LIVED ON THE CONTINENT OF PANGAEA

When dinosaurs first appeared, the landmasses of the Earth were joined into a supercontinent called Pangaea. This later fractured into two continents – Laurasia and Gondwana.


Camposaurus
Late Triassic
North America
Riojasaurus
Late Triassic
South America
Torvosaurus
Late Jurassic,
North America,
Europe
Apatosaurus
Late Jurassic
North America
Stegosaurus
Late Jurassic
North America,
Europe
TRIASSIC 252–201 MILLION YEARS AGO
JURASSIC 201–145 MILLION YEARS AGO

DID YOU KNOW? *A theropod known as Concavenator had a hump on its back like a camel*

52 THERE WERE MORE THAN 700 SPECIES OF DINOSAUR

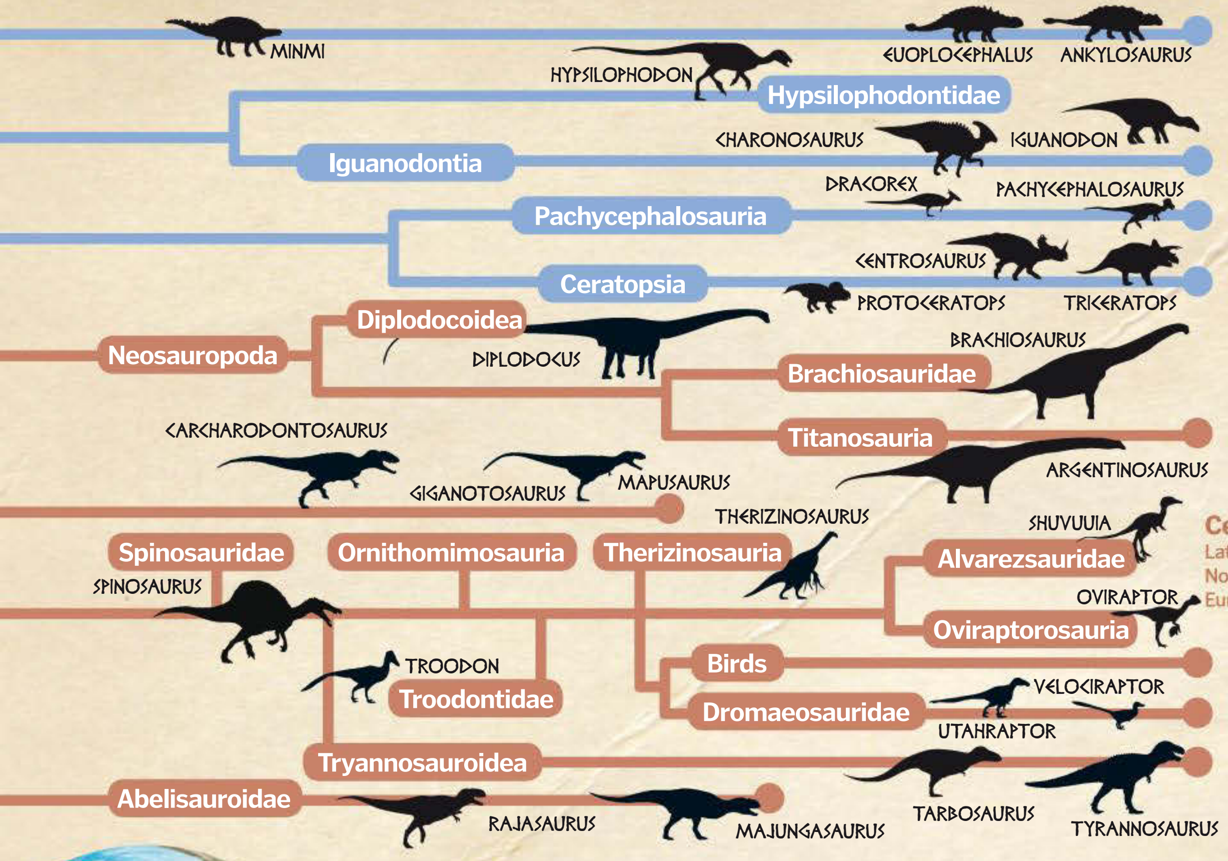
To date, over 700 dinosaur species have been identified, but only 300 or so have been confirmed as unique. With more to be found, this number will continue to change.

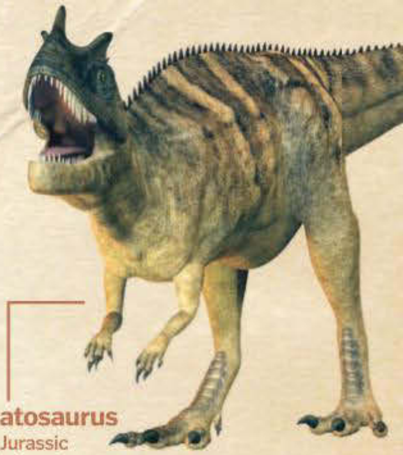
53 THERE ARE HUNDREDS OF DINOSAURS YET TO BE FOUND

It is estimated that we have found only a tenth of the dinosaur species that existed. Some are buried in inaccessible rocks, while others lived in areas that did not favour fossil formation.

54 THERE WERE FEWER DINOSAUR SPECIES THAN WE THOUGHT

Hundreds of species of dinosaur have been named, but very few baby dinosaurs have ever been found. Scientists have reviewed the evidence again and have found that some smaller species might actually be the babies of larger species, and that as they grew their head and body shapes changed.


MINMI
EUOPLOCEPHALUS
ANKYLOSAURUS
HYPSILOPHODON
Hypsilophodontidae
CHARONOSAURUS
IGUANODON
Iguanodontia
DRACOREX
PACHYCEPHALOSAURUS
Pachycephalosauria
CENTROSAURUS
Ceratopsia
PROTOCERATOPS
TRICERATOPS
Diplodocoidea
Neosauropoda
DIPLODOCUS
BRACHIOSAURUS
Brachiosauridae
CARCHARODONTOSAURUS
Titanosauria
GIGANOTOSAURUS
MAPUSAURUS
ARGENTINOSAURUS
THERIZINOSAURUS
SHUVUUIA
Spinosauridae
Ornithomimosauria
Therizinosauria
Alvarezsauridae
SPINOSAURUS
OVIRAPTOR
Oviraptorosauria
TROODON
Troodontidae
Birds
VELOCIRAPTOR
Dromaeosauridae
UTAHRAPTOR
Tryannosauroidea
Abelisauroidae
RAJASAURUS
MAJUNGASAURUS
TARBOSAURUS
TYRANNOSAURUS



Ceratosaurus
Late Jurassic
North America,
Europe

55 DINOSAURS ARE STILL ALIVE TODAY

In the 19th century the fossilised remains of a feathered dinosaur called Archaeopteryx were discovered, and since then evidence linking dinosaurs to birds has stacked up. It is thought that early birds started to evolve from the carnivorous theropods in the late Jurassic, and a few managed to survive the mass extinction, giving rise to the bird species we see today.

© Thinkstock; Science Photo Library

60 SEA LEVELS WERE AT AN ALL-TIME HIGH IN THE CRETACEOUS

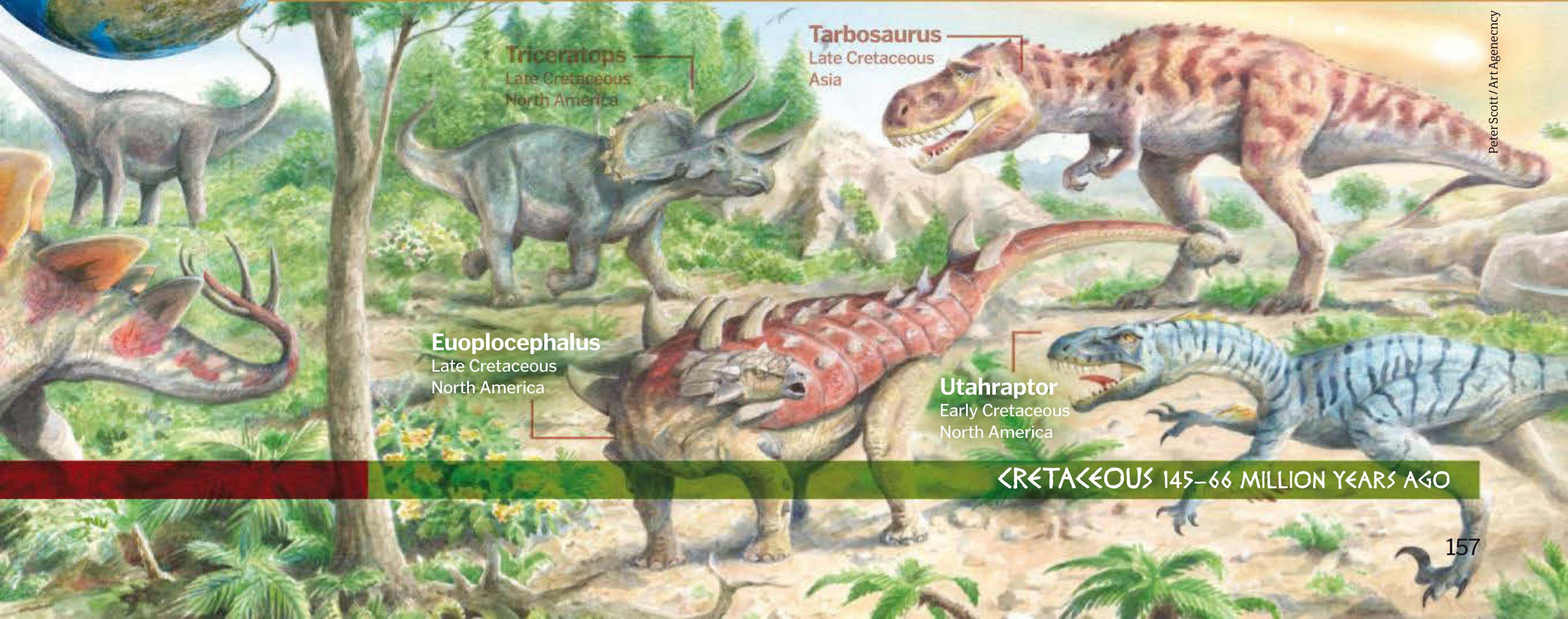
During the Cretaceous period, sea levels rose and fell dramatically, and large areas of land disappeared under water. At times the sea was 100-250m (330-820ft) higher than it is today.

61 HIGH OXYGEN LEVELS FUELLED FIRES DURING THE EXTINCTION EVENT

During the Cretaceous period, oxygen levels in the atmosphere were much higher than they are now, which may have helped to fuel fires after the famous meteor impact 66 million years ago, contributing to the mass extinction.

62 THEY EXPERIENCED MORE THAN ONE MASS EXTINCTION

There was a mass extinction at the end of the Triassic period, when many land animals died out, leaving room for the evolution of some of the giants of the dinosaur world.



Triceratops
Late Cretaceous
North America

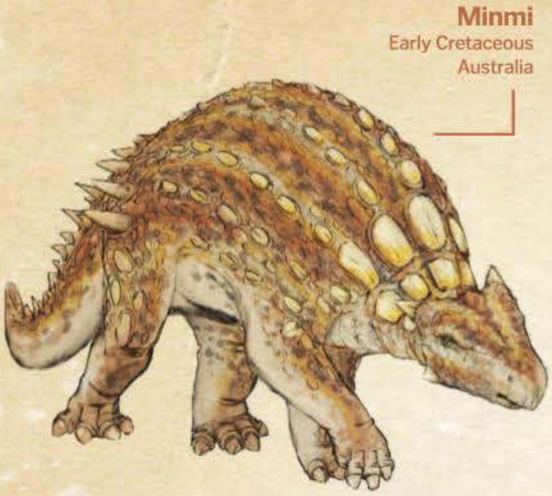
Tarbosaurus
Late Cretaceous
Asia

Euoplocephalus
Late Cretaceous
North America

Utahraptor
Early Cretaceous
North America

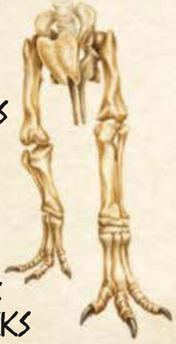
CRETACEOUS 145–66 MILLION YEARS AGO

Peter Scott / Art Agenecny



63 ARMOURED DINOSAURS ARE KNOWN AS 'THYREOPHORA'

Stegosaurus and Ankylosaurus are famous for their armour plating and were members of a group of dinosaurs called Thyreophora. Anklosauria were the most heavily armoured and had bony plates, spikes and clubbed tails.



64 DINOSAUR'S LEGS ARE POSITIONED BENEATH THEIR BODIES

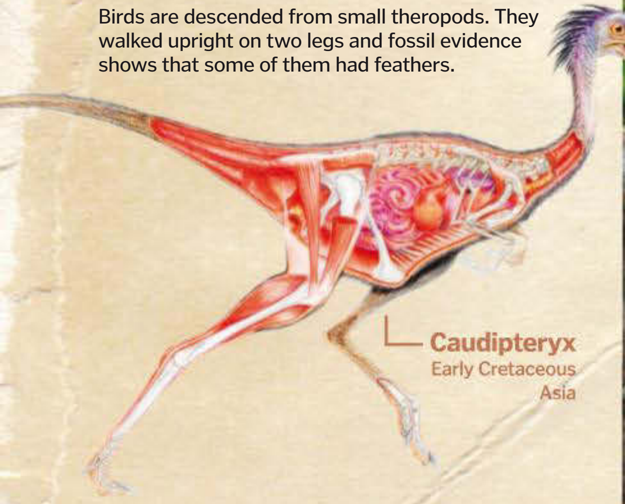
Crocodiles and lizards walk with their legs out to the sides, but dinosaurs have their legs underneath their bodies, allowing them to run faster.

65 SOME DINOSAURS SWALLOWED ROCKS

Many plant-eating dinosaurs have been found with groups of rounded stones inside their ribcages, indicating they swallowed stones to aid digestion, like modern birds.

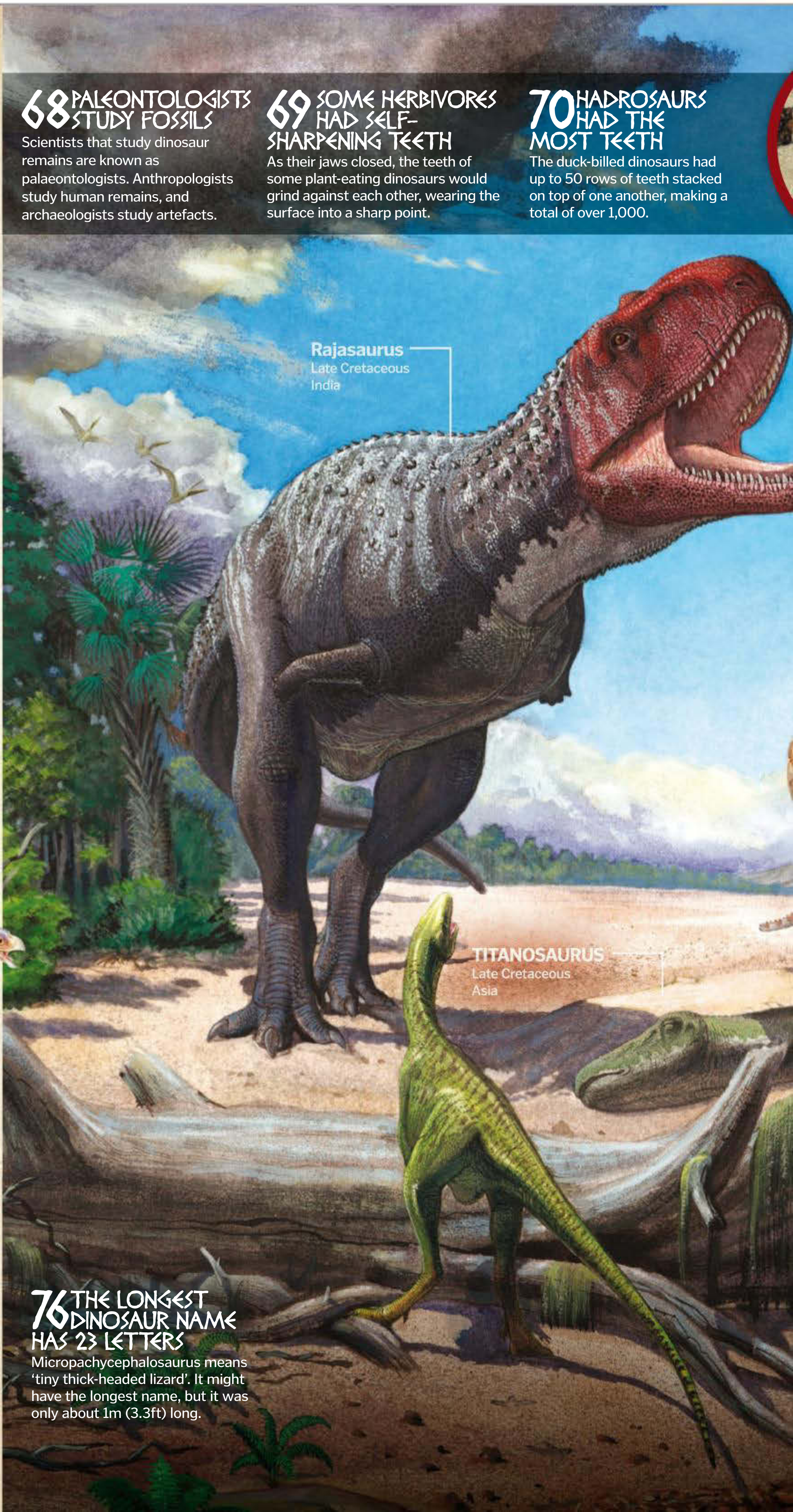
66 SOME DINOSAURS HAD A MIXTURE OF DINOSAUR-LIKE AND BIRD-LIKE FEATURES

Birds are descended from small theropods. They walked upright on two legs and fossil evidence shows that some of them had feathers.



67 DINOSAURS LIVED IN A CHANGING WORLD

Around 250 million years ago, all of Earth's landmasses were joined in a supercontinent known as Pangaea. During the reign of the dinosaurs, this landmass split apart, first into two and then into the seven continents we see today.



68 PALEONTOLOGISTS STUDY FOSSILS

Scientists that study dinosaur remains are known as palaeontologists. Anthropologists study human remains, and archaeologists study artefacts.

69 SOME HERBIVORES HAD SELF-SHARPENING TEETH

As their jaws closed, the teeth of some plant-eating dinosaurs would grind against each other, wearing the surface into a sharp point.

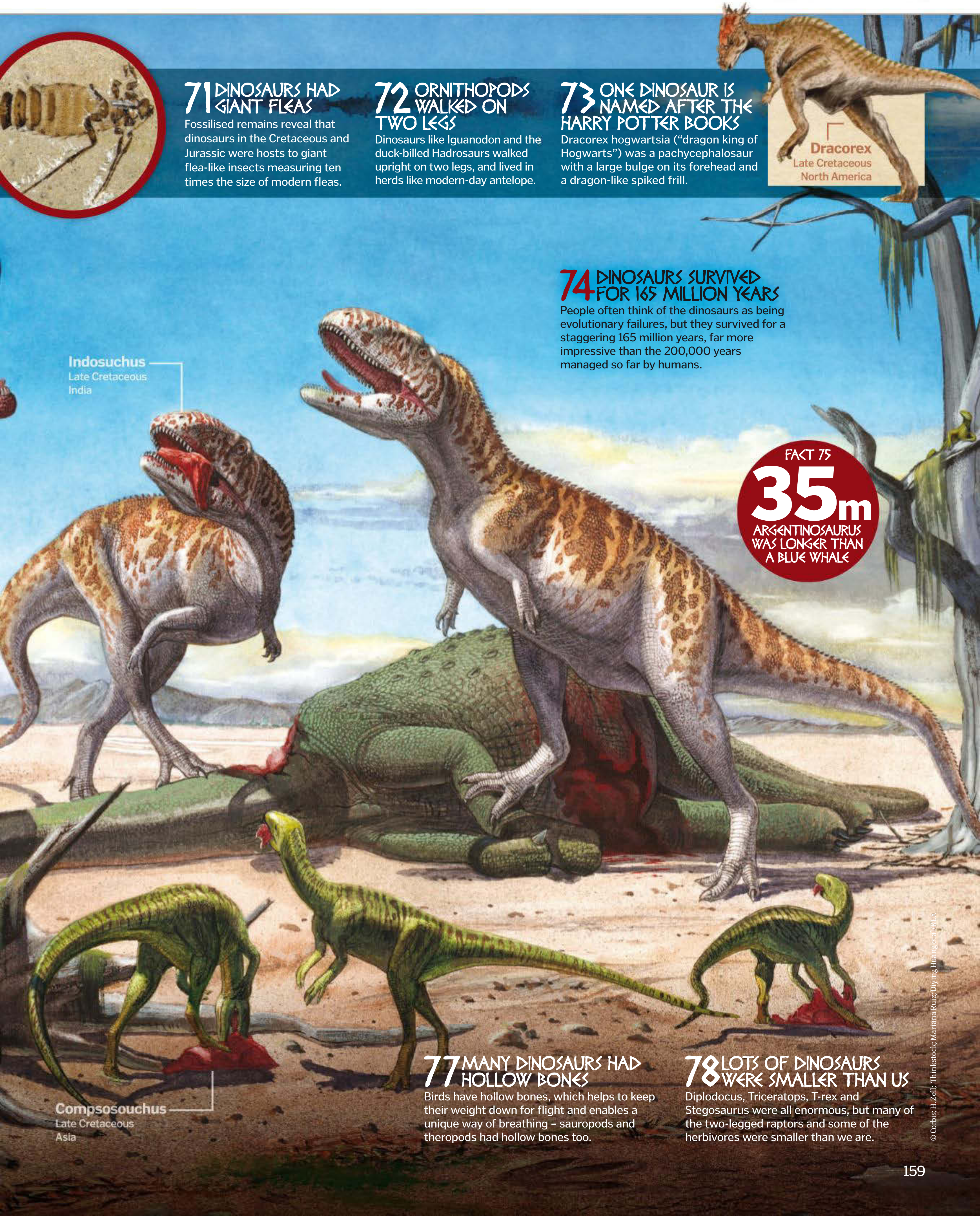
70 HADROSAURS HAD THE MOST TEETH

The duck-billed dinosaurs had up to 50 rows of teeth stacked on top of one another, making a total of over 1,000.

76 THE LONGEST DINOSAUR NAME HAS 23 LETTERS

Micropachycephalosaurus means 'tiny thick-headed lizard'. It might have the longest name, but it was only about 1m (3.3ft) long.

DID YOU KNOW? *In 2005, collagen tissue was found in a T-rex fossil. Scientists think iron molecules helped prevent its decay*



71 DINOSAURS HAD GIANT FLEAS

Fossilised remains reveal that dinosaurs in the Cretaceous and Jurassic were hosts to giant flea-like insects measuring ten times the size of modern fleas.

72 ORNITHOPODS WALKED ON TWO LEGS

Dinosaurs like Iguanodon and the duck-billed Hadrosaurs walked upright on two legs, and lived in herds like modern-day antelope.

73 ONE DINOSAUR IS NAMED AFTER THE HARRY POTTER BOOKS

Dracorex hogwartsia ("dragon king of Hogwarts") was a pachycephalosaur with a large bulge on its forehead and a dragon-like spiked frill.

74 DINOSAURS SURVIVED FOR 165 MILLION YEARS

People often think of the dinosaurs as being evolutionary failures, but they survived for a staggering 165 million years, far more impressive than the 200,000 years managed so far by humans.

FACT 75

35m

ARGENTINOSAURUS WAS LONGER THAN A BLUE WHALE

77 MANY DINOSAURS HAD HOLLOW BONES

Birds have hollow bones, which helps to keep their weight down for flight and enables a unique way of breathing – sauropods and theropods had hollow bones too.

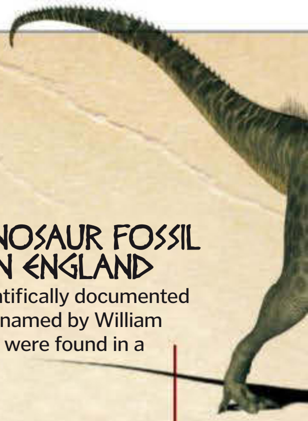
78 LOTS OF DINOSAURS WERE SMALLER THAN US

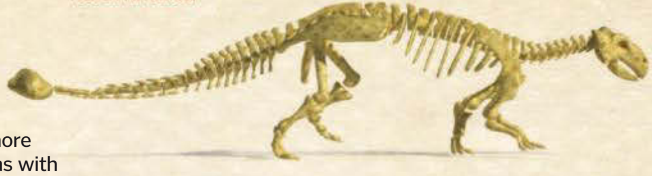
Diplodocus, Triceratops, T-rex and Stegosaurus were all enormous, but many of the two-legged raptors and some of the herbivores were smaller than we are.

© Corbis; H. Zell; Thinkstock; Mariana Ruiz; Diying Huang et al/REX

HUNTING DINOSAURS

Fossils have be found on every continent on Earth...



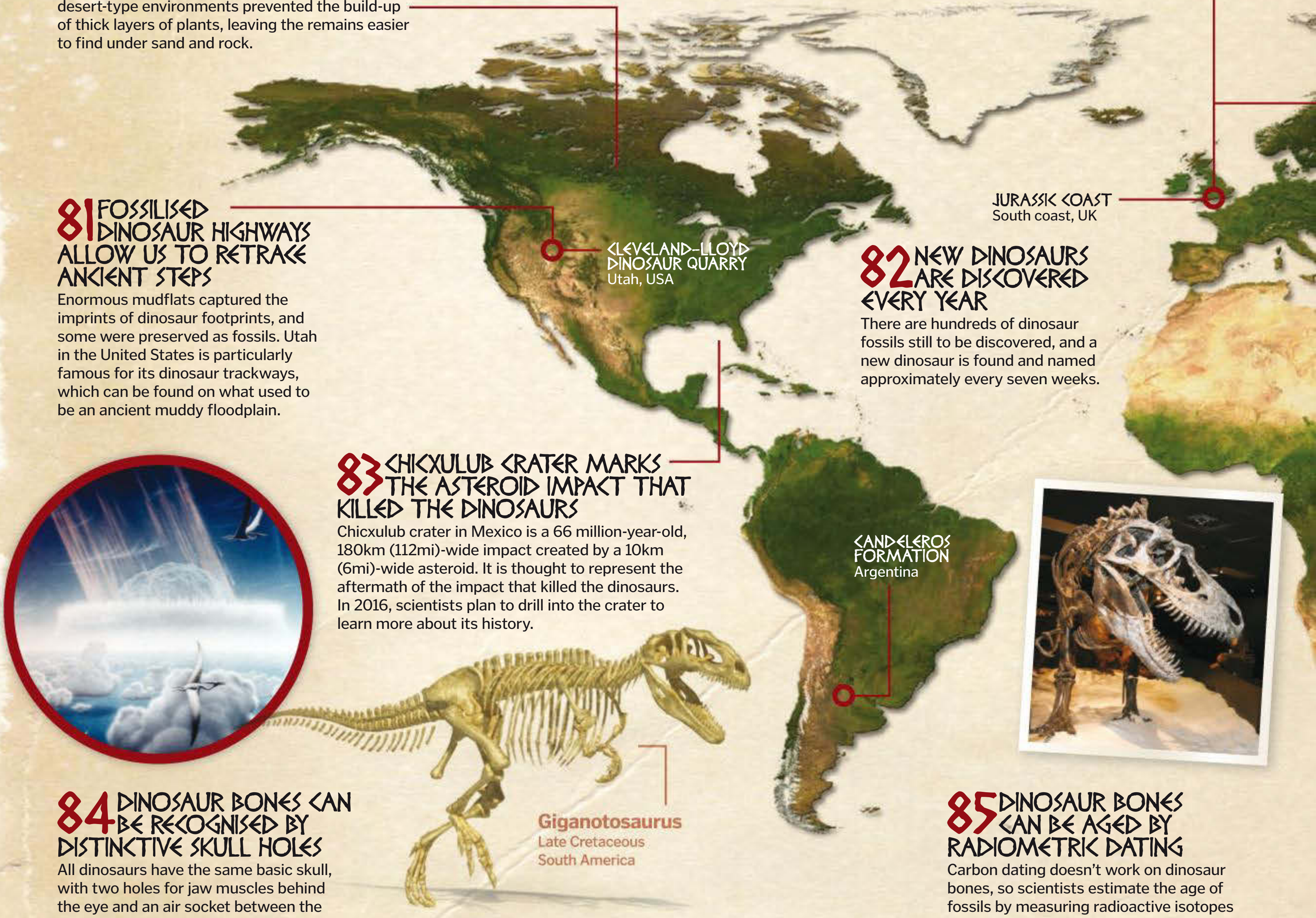


79 NORTH AMERICA HAS EXCAVATED THE MOST DINOSAUR FOSSILS

North America, Argentina and China have more than their fair share of dinosaur fossils. Areas with desert-type environments prevented the build-up of thick layers of plants, leaving the remains easier to find under sand and rock.

80 THE FIRST DINOSAUR FOSSIL WAS FOUND IN ENGLAND

The first dinosaur to be scientifically documented was Megalosaurus, formally named by William Buckland in 1824. The fossils were found in a quarry in Oxford.



81 FOSSILISED DINOSAUR HIGHWAYS ALLOW US TO RETRACE ANCIENT STEPS

Enormous mudflats captured the imprints of dinosaur footprints, and some were preserved as fossils. Utah in the United States is particularly famous for its dinosaur trackways, which can be found on what used to be an ancient muddy floodplain.

82 NEW DINOSAURS ARE DISCOVERED EVERY YEAR

There are hundreds of dinosaur fossils still to be discovered, and a new dinosaur is found and named approximately every seven weeks.

83 CHICXULUB CRATER MARKS THE ASTEROID IMPACT THAT KILLED THE DINOSAURS

Chicxulub crater in Mexico is a 66 million-year-old, 180km (112mi)-wide impact created by a 10km (6mi)-wide asteroid. It is thought to represent the aftermath of the impact that killed the dinosaurs. In 2016, scientists plan to drill into the crater to learn more about its history.

84 DINOSAUR BONES CAN BE RECOGNISED BY DISTINCTIVE SKULL HOLES

All dinosaurs have the same basic skull, with two holes for jaw muscles behind the eye and an air socket between the eyes and nose.

85 DINOSAUR BONES CAN BE AGED BY RADIOMETRIC DATING

Carbon dating doesn't work on dinosaur bones, so scientists estimate the age of fossils by measuring radioactive isotopes in the surrounding rocks.

95 DINOSAURS WEREN'T THE FIRST REPTILES TO RULE THE EARTH

Around 300 million years ago amphibians dominated the planet, but as the climate got warmer, reptiles took over. There were the 'bowl lizards' or pelycosaurs, mammal-like reptiles called therapsids, and archosaurs, from which dinosaurs, crocodiles and pterosaurs eventually evolved.

96 DINOSAURS LIVED FOR UP TO 300 YEARS

Paleontologists estimate the large dinosaurs had life spans ranging from 75 to 300 years. However, these estimates were made based on information we have about cold-blooded animals – if they were warm-blooded they would have had shorter lives.

97 TROODONS WERE PROBABLY THE CLEVEREST DINOSAURS

Troodons lived around 77 million years ago and were about two metres (6.6 feet) long. They were carnivores, walked on two legs and had relatively large brains for their body size. They are also thought to be related to modern birds.

98 AMBER INSECTS DON'T CONTAIN DINOSAUR DNA

Jurassic Park is based on the idea that you could extract dinosaur DNA from blood preserved inside the bodies of mosquitoes encased in amber. Unfortunately, despite several attempts to recover DNA from preserved insects, it seems as though it doesn't actually survive inside the amber.

86 MORE THAN 100 DIFFERENT DINOSAURS LIVED IN BRITAIN

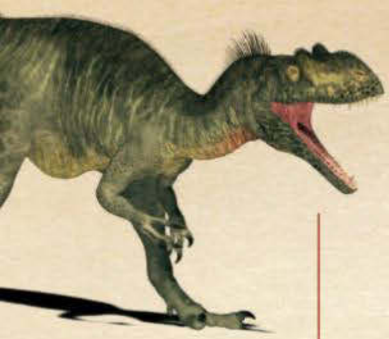
Britain used to form a land bridge that connected Europe to North America, and has been described as a dinosaur paradise. It was home to over 100 different species, including armoured ankylosaurs, giant sauropods and three different types of fearsome tyrannosaur.

87 THERE'S NO ACTUAL BONE IN A DINOSAUR FOSSIL

When dinosaurs died, their bones were covered in sediment that was compressed and turned to rock. Over time, the bone itself dissolved away, leaving a bone-shaped hole in the rock, which then filled with minerals, forming a cast.

88 MOST DINOSAUR FOSSILS WERE FOUND BY AMATEURS

There are many more amateur fossil hunters than professionals, and they can cover much more ground. The largest T-rex fossil ever was found by an amateur.

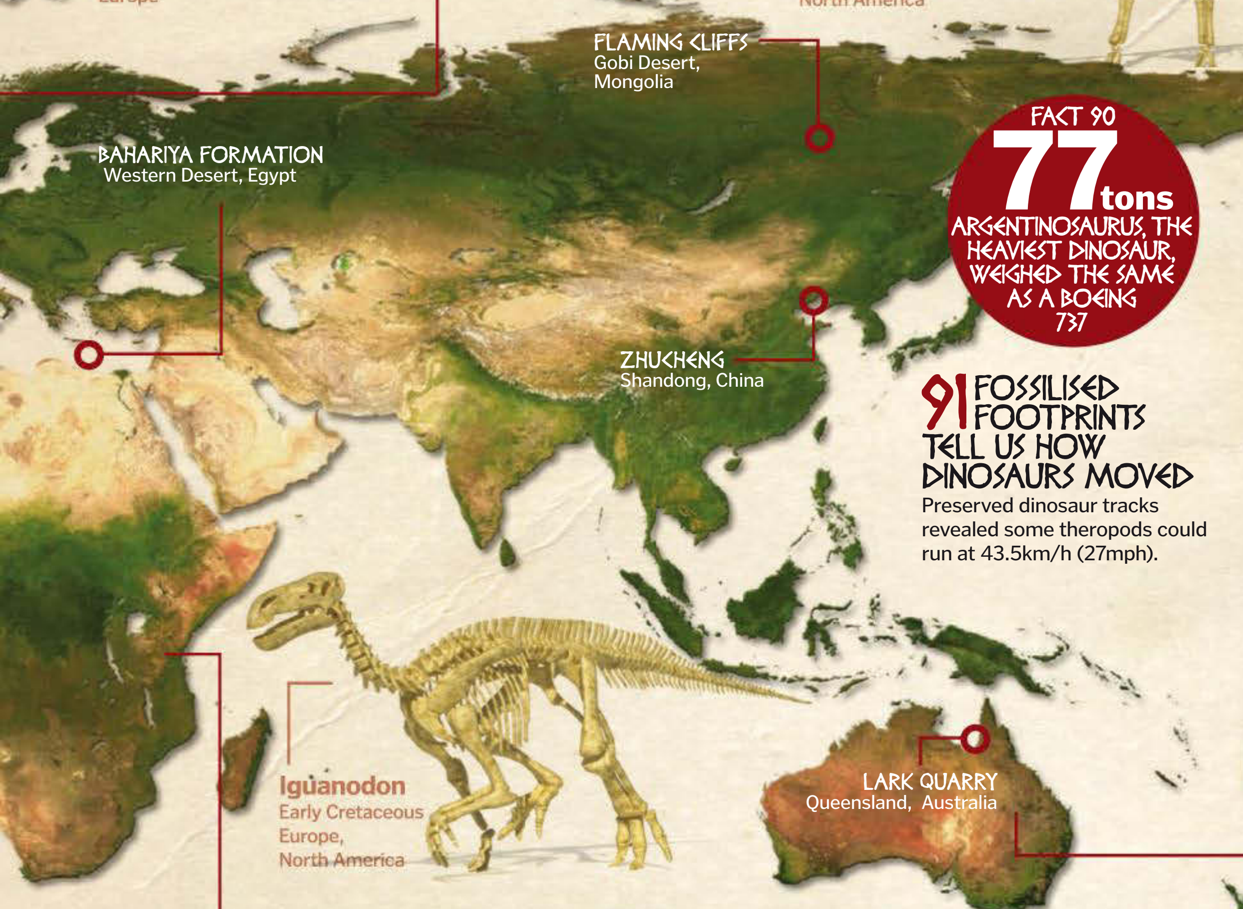


Megalosaurus
Mid Jurassic
Europe

Diplodocus
Late Jurassic
North America

89 THERE ARE TWO MAIN TYPES OF FOSSIL

Body fossils show the actual shape of dinosaur remains, while trace fossils show evidence of their lives, like footprints and nests.



Iguanodon
Early Cretaceous
Europe,
North America

FACT 90

77tons

ARGENTINOSAURUS, THE HEAVIEST DINOSAUR, WEIGHED THE SAME AS A BOEING 737

91 FOSSILISED FOOTPRINTS TELL US HOW DINOSAURS MOVED

Preserved dinosaur tracks revealed some theropods could run at 43.5km/h (27mph).

92 DINOSAURS RAN ALONG RIVERBEDS

Fossilised dinosaur tracks found in Australia reveal a superhighway where two-legged dinosaurs travelled on tiptoe through a fast-moving river.

93 THE MOST ANCIENT DINOSAUR FOSSILS WERE FOUND IN TANZANIA

One of the earliest-ever dinosaur fossils found is a 243-million-year-old dog-sized dinosaur called Nyasasaurus parringtoni. Bones from two different individuals were excavated in the 1930s, but weren't properly studied until 2012.

94 DINOSAUR FOSSILS ARE FOUND ON ALL SEVEN CONTINENTS

Dinosaur fossils have been found in the very northern parts of Canada, right down to the frozen wastes of Antarctica.

Utahraptor
Early Cretaceous
North America

99 RAPTORS WERE COVERED IN FEATHERS

Of all the dinosaurs, the most feathery were the theropods. Velociraptors were covered in a layer of feathers, and so too was T-rex. Many other dinosaurs had spiny quills or feathery stubs.

100 MAMMALS USED TO EAT DINOSAURS

Repenomamus robustus was a 1m (3.3ft)-long mammal that lived 125 million years ago in China. One specimen was found with dinosaur remains inside it.

101 BRONTOSAURUS MIGHT HAVE BEEN A REAL DINOSAUR AFTER ALL

Brontosaurus is famous for not being a real dinosaur – the fossils were mixed up and the head of a Camarasaurus was placed on the body of an Apatosaurus. However, in 2015, a new study of the bones revealed that Brontosaurus has a longer and thinner neck than Apatosaurus and thus might be a distinct species after all.

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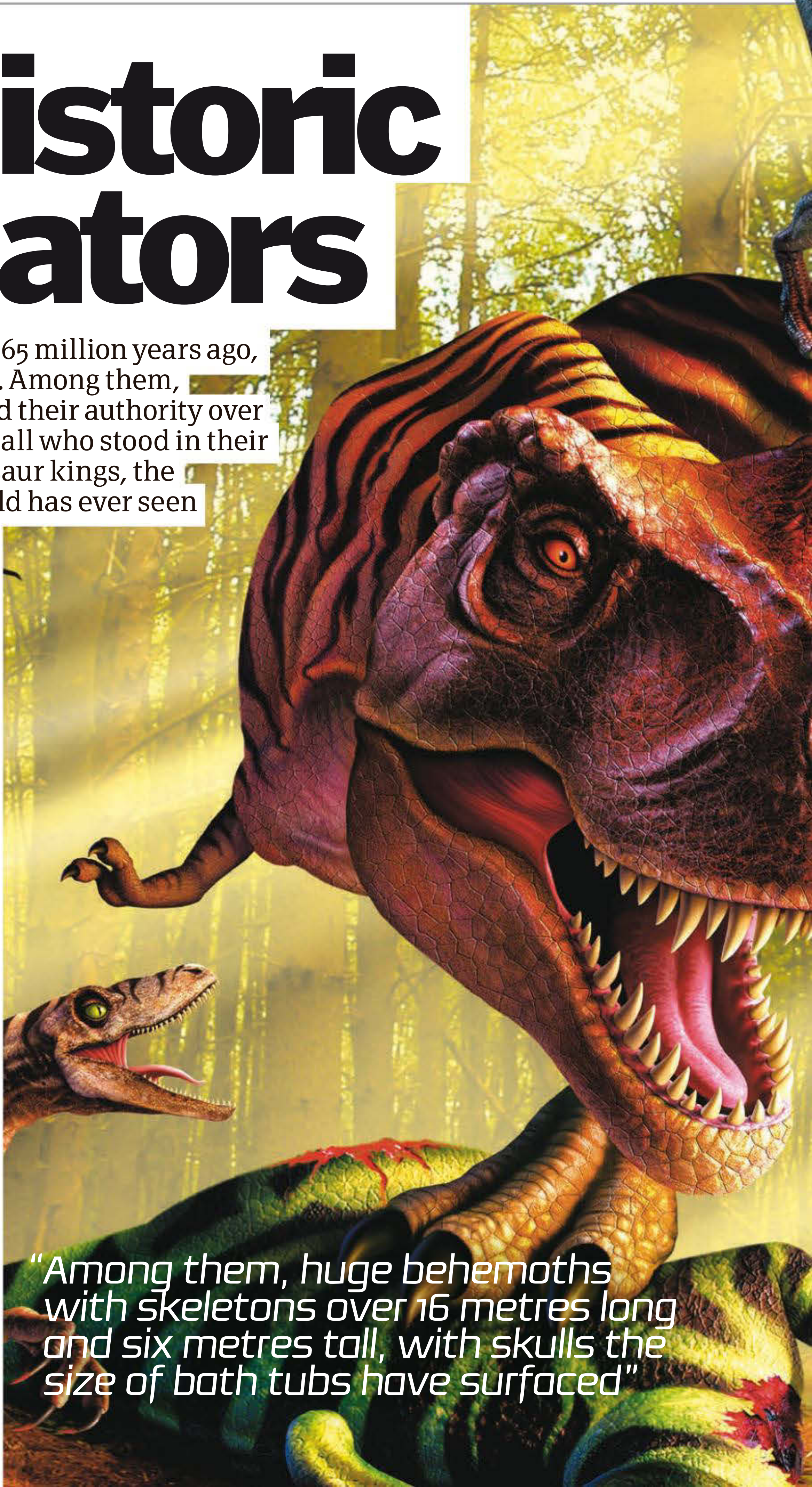
Prehistoric predators

Until they were wiped out 65 million years ago, dinosaurs ruled the Earth. Among them, monstrous beasts stamped their authority over the menagerie, devouring all who stood in their way. These were the dinosaur kings, the largest carnivores the world has ever seen



Evolving from archosaurs (large lizards) in the latter part of the middle Triassic period, dinosaurs quickly gained a strong and prolific foothold all over Pangaea, the super continent which all our continents were once part of. Indeed, as the dominant terrestrial vertebrates through the Jurassic and Cretaceous periods, thousands of species of dinosaur have been unearthed as fossils by palaeontologists all over the world, with new discoveries being presented every year. Among them, huge behemoths with skeletons over 16 metres long and six metres tall, with skulls the size of bath tubs have surfaced and delivered a scary and disturbing glimpse into the creatures that once prowled the countries we still live in today.

Among the largest of these giants, a group of massive carnivorous theropods (bipedal dinosaurs) emerged throughout the Jurassic and Cretaceous periods, casting a shadow over the rest of the dinosaur population. The most famous of these is the Tyrannosaurus rex, as made popular by the Jurassic Park films, however this type of theropod was but one of a host of killers and, amazingly, not the largest! Historically, of course, the reign of these carnivorous kings was cut short in the mass-extinction of the dinosaur population at the close of the Cretaceous period, when a 110-mile radius asteroid crashed into the Yucatán Peninsula, setting off a chain-reaction (tsunamis, dust clouds, temperature variation, food-chain collapse) of events that eventually led to their extermination.

Here, though, we explore the giddy heights of the pinnacle of dinosaur evolution, the time when nothing on Earth could match these beasts for size and strength. Better run for cover then, as things are about to get prehistoric…

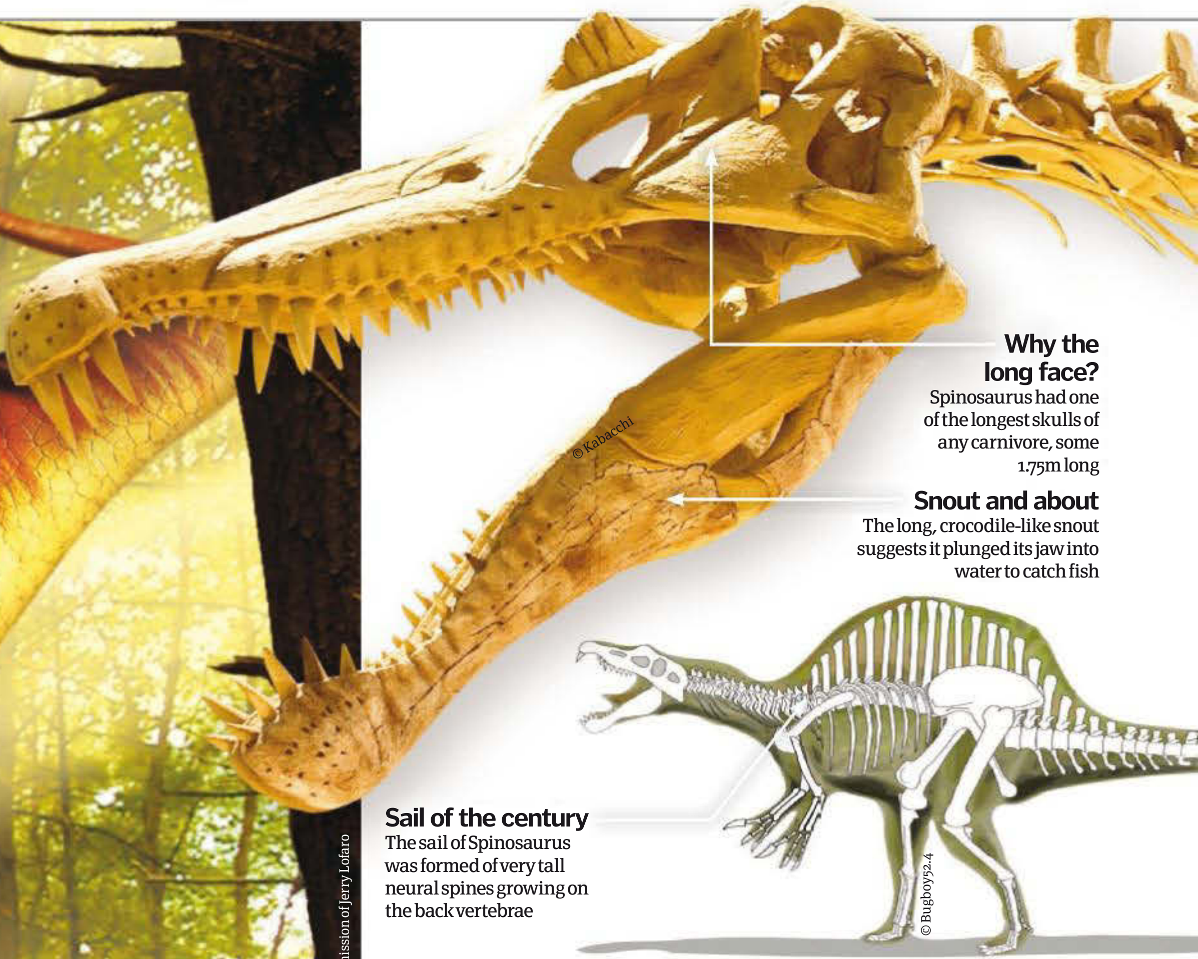
> "Among them, huge behemoths with skeletons over 16 metres long and six metres tall, with skulls the size of bath tubs have surfaced"

Image used with kind permission of Jerry Lofaro

The Statistics

Spinosaurus

Height: 6 metres
Length: 16 metres
Weight: 12 tons
Head size: 1.75 metres
Interesting fact: The spines on the Spinosaurus grew up to two metres tall
Fear factor: 9/10



© Kabacchi

Why the long face?
Spinosaurus had one of the longest skulls of any carnivore, some 1.75m long

Snout and about
The long, crocodile-like snout suggests it plunged its jaw into water to catch fish

Sail of the century
The sail of Spinosaurus was formed of very tall neural spines growing on the back vertebrae

© Bugboy52.4

CARNIVORE 1

Spinosaurus

Step aside T-rex, this was the ultimate theropod…

Bigger and arguably meaner than the Tyrannosaurus rex, the Spinosaurus is thought to be the largest theropod dinosaur to ever roam the planet. Over 16 metres long, six metres high and weighing a monumental 12 tons, the Spinosaurus was a relatively common animal in the late Cretaceous period. Palaeontologists have found fossilised remains of the Spinosaurus in Morocco, Libya and Egypt, including a well preserved but now destroyed (blown-up in a World War II bombing run) specimen that included the lower jaw and vertebrae with complete spines. Spinosaurus was typical for a large theropod but differed in its skull and vertebrae construction. The snout of the 1.75-metre skull was long like a crocodile, with the nostril openings placed well back from the tip. Its teeth were also conical, rounded in a cross section and did not contain any serrations – these features suggest that the Spinosaurus plunged its jaw into water in order to catch fish. However, considering its size, jaw strength and number of teeth, it equally had no trouble in hunting small, medium and other large dinosaurs on land.

Not a dinosaur you'd want to meet down a dark alley…

CARNIVORE 2

Giganotosaurus

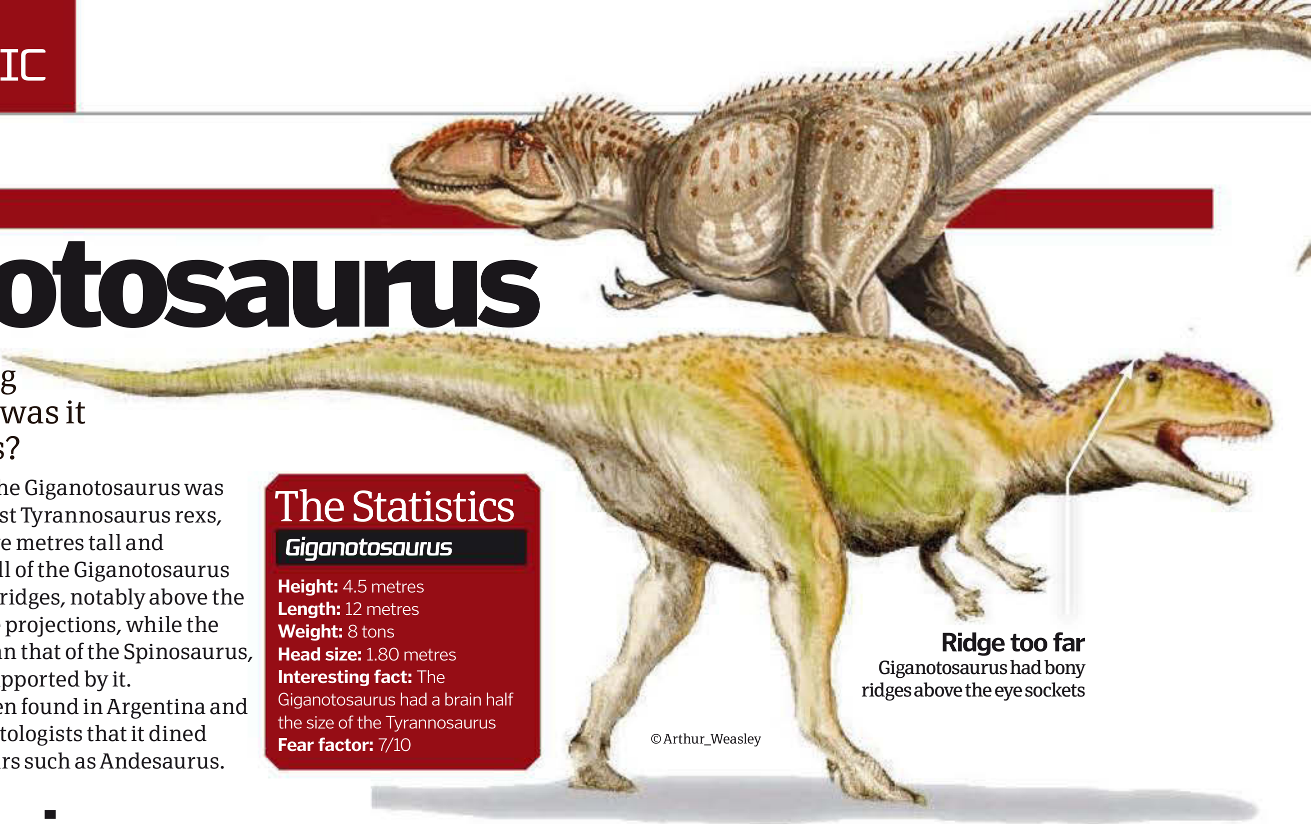
The dinosaur with a big name to live up to, but was it as colossal as it sounds?

Meaning 'giant southern lizard', the Giganotosaurus was roughly the same size as the largest Tyrannosaurus rexs, measuring over 12 metres long, five metres tall and weighing over eight tons. The skull of the Giganotosaurus was adorned with shelf-like bony ridges, notably above the eye sockets and had low horn-like projections, while the neck was considerably thicker than that of the Spinosaurus, with a stout and powerful head supported by it. Giganotosaurus remains have been found in Argentina and it has been postulated by palaeontologists that it dined mainly on medium-sized dinosaurs such as Andesaurus.

The Statistics

Giganotosaurus

Height: 4.5 metres
Length: 12 metres
Weight: 8 tons
Head size: 1.80 metres
Interesting fact: The Giganotosaurus had a brain half the size of the Tyrannosaurus
Fear factor: 7/10

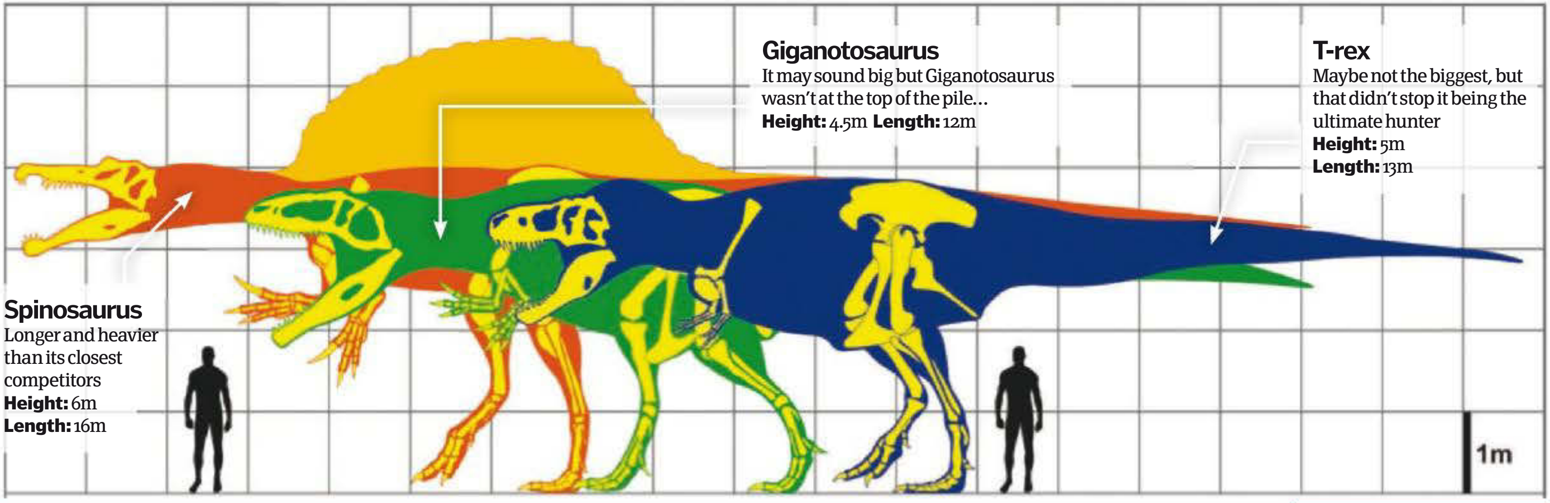


Ridge too far
Giganotosaurus had bony ridges above the eye sockets

© Arthur_Weasley

Size comparison

Who was the real king of the dinosaurs…



Giganotosaurus
It may sound big but Giganotosaurus wasn't at the top of the pile…
Height: 4.5m **Length:** 12m

T-rex
Maybe not the biggest, but that didn't stop it being the ultimate hunter
Height: 5m
Length: 13m

Spinosaurus
Longer and heavier than its closest competitors
Height: 6m
Length: 16m

CARNIVORE 3

Carcharodontosaurus

Not the world's easiest name to pronounce…

Named in 1931, the African Carcharodontosaurus was a huge theropod with serrated teeth similar to the great white shark. The skull of the Carcharodontosaurus was very narrow although it reached up to 1.6 metres in length, while its body was taller at the back than at the front, giving it a low, streamlined physicality. The thigh muscles of the Carcharodontosaurus were some of the largest of any dinosaur and this, in partnership with its narrow streamlined frame and ferocious sharp teeth, made chasing down and devouring prey elementary. Arguably the quickest of the carnivorous theropods, the Carcharodontosaurus was a fearsome predator. Fossilised remains have been found in Morocco, Tunisia and Egypt

The Statistics

Carcharodontosaurus

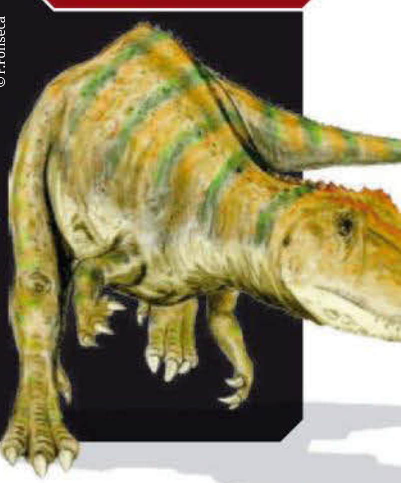
Height: 4 metres
Length: 11 metres
Weight: 6 tons
Head size: 1.60 metres
Interesting fact: The Carcharodontosaurus could run over 20mph
Fear factor: 8/10

© Didier Descovens 2010

This incredible beast was named after its deadly serrated teeth

Shark-like teeth
The serrations in the teeth are very similar to a shark's

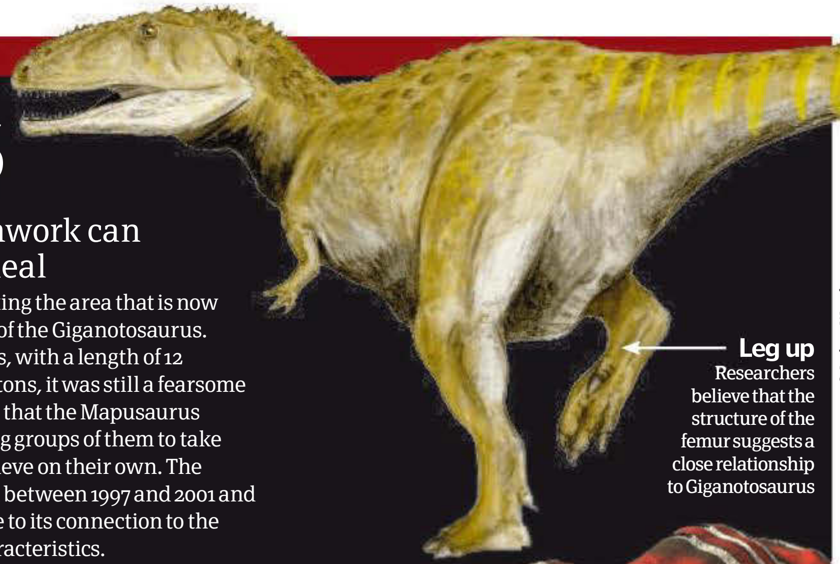
© F.Fonseca



© Arthur_Weasley

CARNIVORE 4

Mapusaurus



Leg up
Researchers believe that the structure of the femur suggests a close relationship to Giganotosaurus

© Arthur_Weasley

The Statistics

Mapusaurus

Height: 4 metres
Length: 12 metres
Weight: 4 tons
Head size: 1 metre
Interesting fact: Unlike other large theropod dinosaurs, Mapusaurus' would often hunt in groups
Fear factor: 6/10

The dinosaur that proved teamwork can be the best way to get a good meal

Dating from the late Cretaceous period and stalking the area that is now Argentina, the Mapusaurus was a close relative of the Giganotosaurus. Despite being one of the smaller giant carnivores, with a length of 12 metres, height of four metres and weight of four tons, it was still a fearsome predator. Interestingly, palaeontologists believe that the Mapusaurus would engage in group hunting activity, allowing groups of them to take down larger foes than they would be able to achieve on their own. The remains of the Mapusaurus were first excavated between 1997 and 2001 and now complete the majority of a full skeleton. Due to its connection to the Giganotosaurus, it shares many of the same characteristics.

CARNIVORE 5

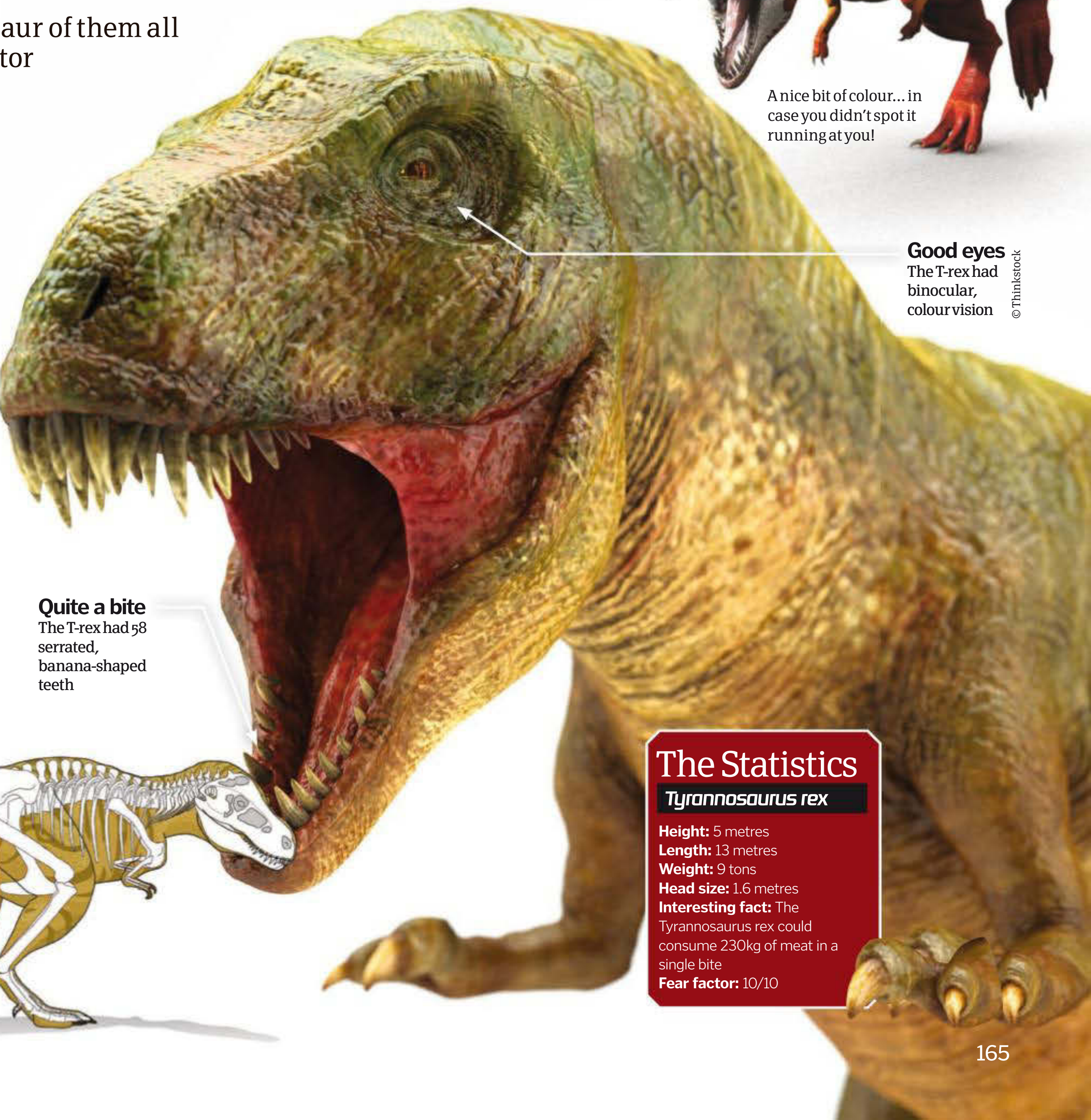
Tyrannosaurus rex

The most famous dinosaur of them all and the ultimate predator

The T-rex was one of the largest terrestrial carnivores in the world, with the estimated strength of its bite greater than that of any other animal that has ever existed on Earth. Standing at a height of five metres, measuring over 13 metres in length and weighing over nine tons, the T-rex is considered to be one of the most fearsome hunters ever.

The body of the T-rex was perfectly balanced, with a horizontal backbone positioned above the hips giving completely equal weight distribution. The head was also colossal, measuring 1.6 metres long and far bulkier than any other theropod, containing 58 serrated teeth and large forward-facing eye sockets giving it acute binocular vision. From fossilised remains of Tyrannosaurus faeces, palaeontologists have discovered that the T-rex crushed bones of the prey it consumed. The T-rex was prolific over the entire western North America.

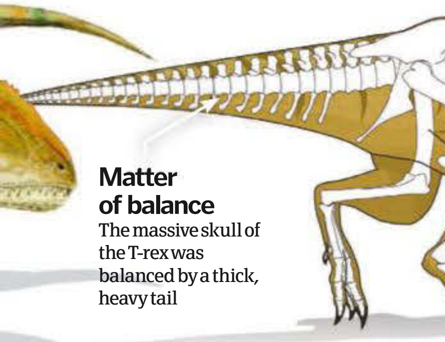
A nice bit of colour… in case you didn't spot it running at you!



Good eyes
The T-rex had binocular, colour vision

© Thinkstock

Quite a bite
The T-rex had 58 serrated, banana-shaped teeth



Matter of balance
The massive skull of the T-rex was balanced by a thick, heavy tail

The Statistics

Tyrannosaurus rex

Height: 5 metres
Length: 13 metres
Weight: 9 tons
Head size: 1.6 metres
Interesting fact: The Tyrannosaurus rex could consume 230kg of meat in a single bite
Fear factor: 10/10

Biggest ever land mammal

Find out how this prehistoric mega-mammal – eight times the size of a modern-day rhinoceros – used to live

Imagine a beast taller than a giraffe and heavier than two elephants. Paraceratherium was the dinosaur of its day. It filled the same ecological niche as the huge sauropod dinosaurs, like Diplodocus, that lived 120 million years earlier, roaming through lightly forested plains and eating the leaves of trees, which it stripped off the branches with its front teeth. Unlike the dinosaurs, Paraceratherium didn't have a very long tail to counterbalance the weight of its neck and head. Instead, it had much more powerful neck muscles, anchored to tall extensions at the top of its spine. This brought its centre of gravity much farther forward, onto the front legs, resulting in a much stockier shape overall.

Paraceratherium lived during the Oligocene epoch, around 30 million years ago. The climate cooled suddenly during this period; Antarctica developed its ice cap for the first time and the Alps began to push upwards to form mountains. As the climate changed, the dense tropical forests were replaced with more open landscapes containing a mixture of trees and grass. These made it harder for medium-sized animals to hide from predators, so natural selection favoured ever-larger individuals able to fend off attacks. Along with competition between males for breeding rights, this drove the evolution of heavier grazing animals. The culmination of this was the Paraceratherium, which weighed a whopping 20 tons.

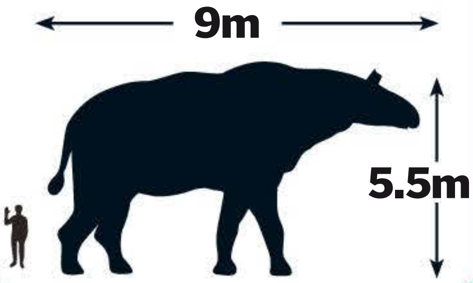
The largest predators at the time were a kind of marsupial hyena, no more than two metres (6.6 feet) long. An adult Paraceratherium was far too large to be troubled by these animals. Instead, they may have been eventually driven extinct by the rise of early elephant species. These would have knocked down the trees Paraceratherium relied on for food. As the grasslands expanded, Paraceratherium was replaced by smaller grazing mammals.

Problems with bone identification

The first Paraceratherium fossil bones were found in 1911 by the palaeontologist Clive Forster Cooper. Two years later, he found more bones he took to be from a related genus and named the animal Baluchitherium because the fossils were found in Baluchistan, in what is now Pakistan. In 1915, Aleksei Borissiak found a third set of bones and named the animal Indricotherium, after the Indrik, a monster from Russian folklore. None of these fossil finds were anything like a full skeleton, and it can be very hard to decide whether you have found a completely new animal or just a larger example of an existing one based on a single neck vertebra. The scientific consensus is now that all three sets of fossils belong to the same genus, which is called Paraceratherium, because this was the first one to be described scientifically. To date, five species of Paraceratherium have been identified.

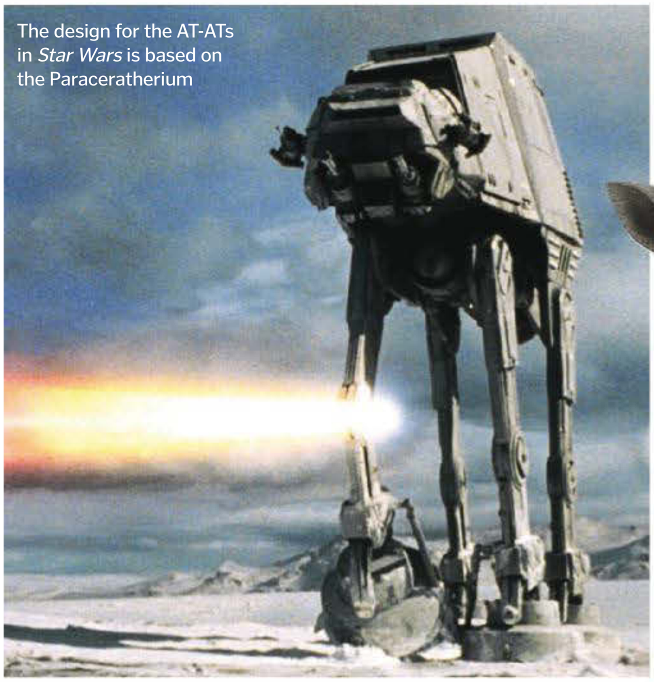
Size matters

How would the Paraceratherium have measured up against a person?



In a galaxy far, far away...

When Phil Tippett was designing the special effects for *Star Wars Episode V: The Empire Strikes Back*, he needed a reference model for the giant mechanical AT-AT walkers that assault the rebel base on Hoth. Initially, his team studied elephants to animate the leg movements, but the final design is much taller and more menacing. That's because they are based on the Paraceratherium. The AT-ATs portrayed in the film are three times as tall as the prehistoric mammal, but the lumbering gait and joint articulation is probably very close to the way the real Paraceratherium would have moved around. It's an interesting prehistoric touch to a futuristic film!

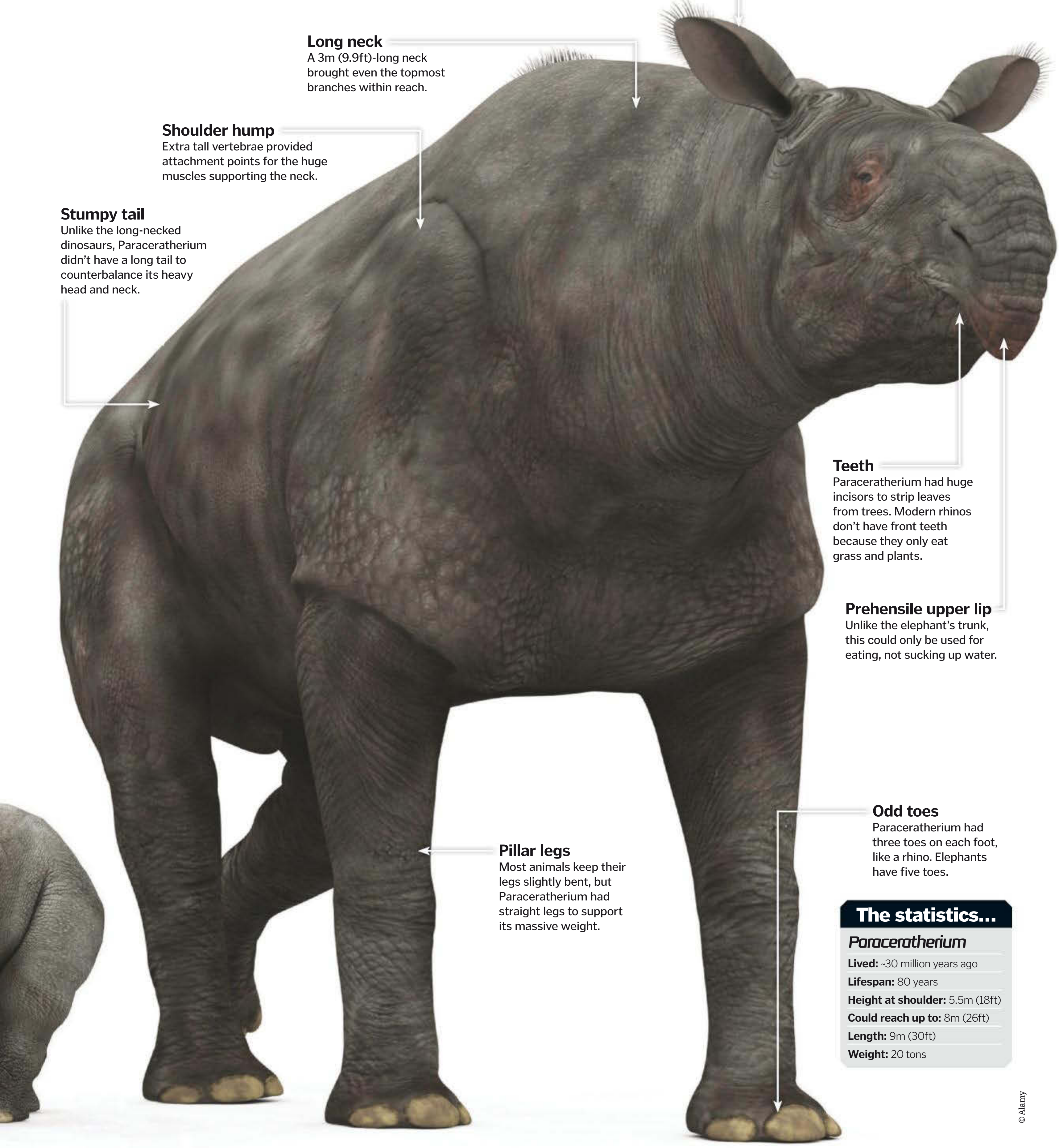

The design for the AT-ATs in *Star Wars* is based on the Paraceratherium

Horn
All modern rhinos have horns for defence, but Paraceratherium was too big to need one.

DID YOU KNOW? *Paraceratherium was bigger than Diplodocus; although the latter was longer, Paraceratherium was bulkier*

Anatomy of a mega-mammal

Paraceratherium may be related to the modern rhino, but there are some sizable differences, as we highlight here...



Mystery ears
Soft ears don't fossilise, but it's possible that Paraceratherium had large flapping ears to keep cool like today's elephants.

Long neck
A 3m (9.9ft)-long neck brought even the topmost branches within reach.

Shoulder hump
Extra tall vertebrae provided attachment points for the huge muscles supporting the neck.

Stumpy tail
Unlike the long-necked dinosaurs, Paraceratherium didn't have a long tail to counterbalance its heavy head and neck.

Teeth
Paraceratherium had huge incisors to strip leaves from trees. Modern rhinos don't have front teeth because they only eat grass and plants.

Prehensile upper lip
Unlike the elephant's trunk, this could only be used for eating, not sucking up water.

Pillar legs
Most animals keep their legs slightly bent, but Paraceratherium had straight legs to support its massive weight.

Odd toes
Paraceratherium had three toes on each foot, like a rhino. Elephants have five toes.

The statistics...

Paraceratherium

Lived: ~30 million years ago

Lifespan: 80 years

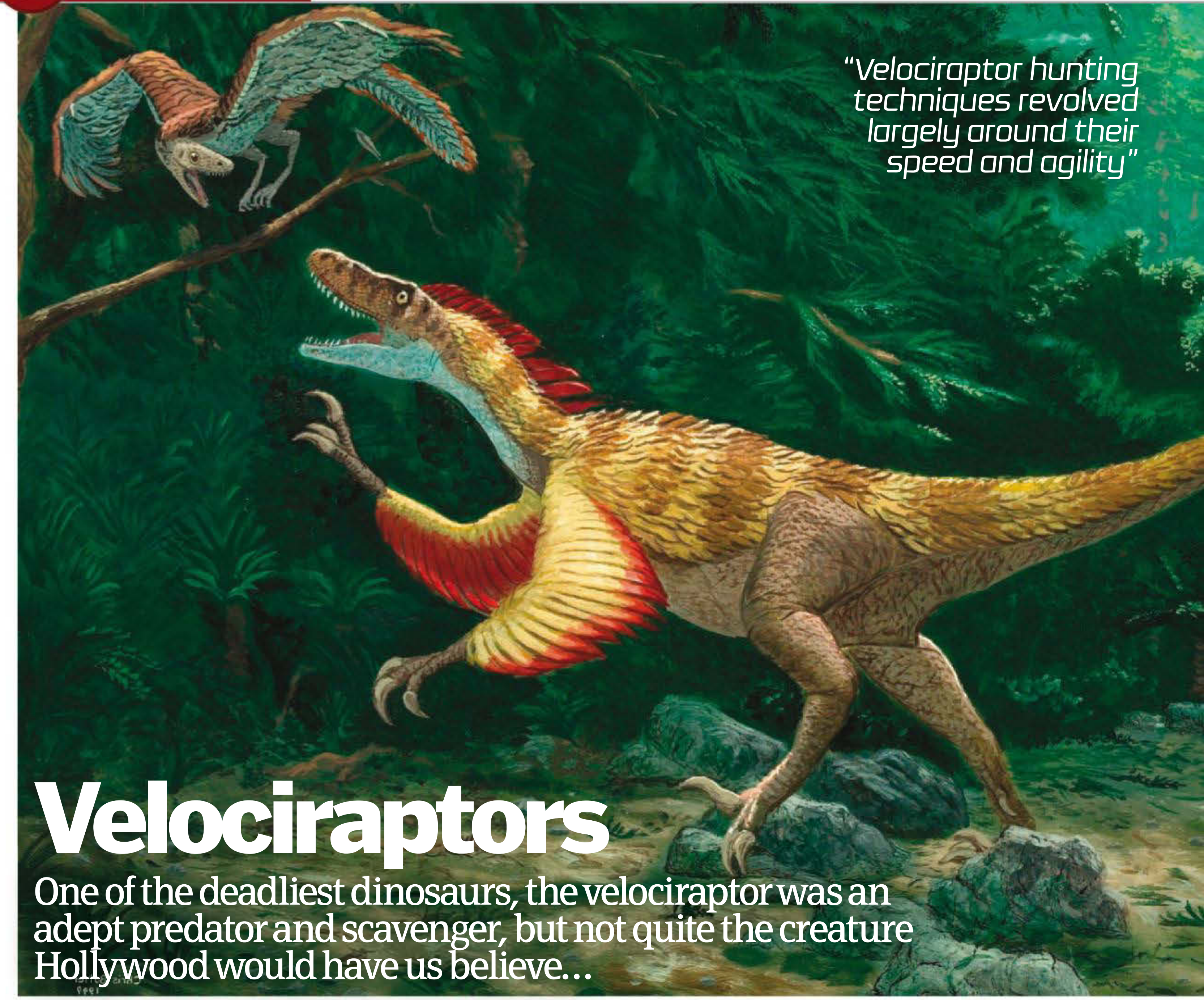
Height at shoulder: 5.5m (18ft)

Could reach up to: 8m (26ft)

Length: 9m (30ft)

Weight: 20 tons

© Alamy



“Velociraptor hunting techniques revolved largely around their speed and agility”

Velociraptors

One of the deadliest dinosaurs, the velociraptor was an adept predator and scavenger, but not quite the creature Hollywood would have us believe…

Velociraptors have been ingrained in public consciousness since the 1993 movie Jurassic Park showcased them as the most fearsome of apex predators. Smart, lethal and bloodthirsty, the velociraptors of the film arguably stole the show. However, the movie was famed for its indulgence of artistic licence, with palaeontologists bemoaning the lack of historical accuracy throughout the movie.

So what were these dinosaurs really like? Velociraptor, of which there are two verified species – V mongoliensis and V osmolskae, was a genus of dromaeosaurid (‘running lizard’) theropod dinosaur that lived in the Late Cretaceous period, about 75-71 million years ago. They were two metres (6.6 feet) long, just under a metre (three feet) high, feathered and bipedal, running on two of their three toes per foot. They were native to modern-day central Asia (notably Mongolia), where they built large, ground-based nests to protect their young.

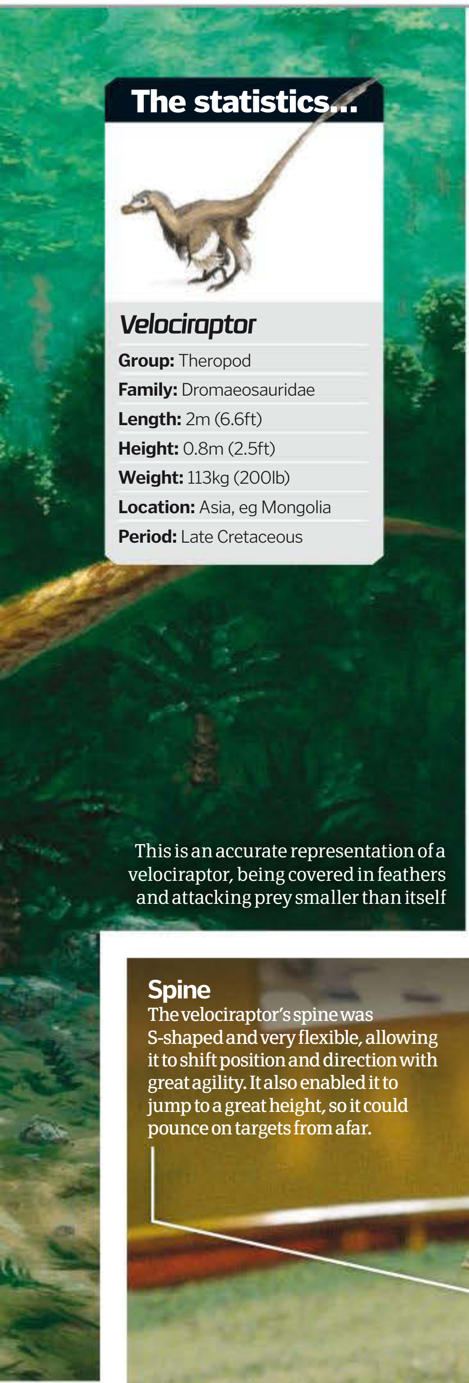
Velociraptors, though often living in close proximity to one another, were largely solitary and, while certain finds suggest they could have teamed up while chasing their quarry, they were not pack hunters, with evidence showing they would fight among themselves for feeding rights. In addition, their staple diet consisted of animals of equal size and weight to themselves or those smaller than them, with very little evidence suggesting they would attempt to bring down larger dinosaurs, such as the Tyrannosaurus rex à la Jurassic Park.

Velociraptor hunting techniques revolved largely around their speed and agility. They could accelerate up to 64 kilometres (40 miles) per hour and pounce long distances, as well as grip prey firmly with their unique, sickle-shaped claws (notably their enlarged ‘killing claw’). These traits were partnered with a tendency to ambush prey, rather than tackle their victims face on or from long range (see the ‘Slash or subdue?’ boxout).

Interestingly, however, while there’s no doubt that velociraptors hunted live prey, unearthed fossilised evidence suggests they were also incredibly active scavengers, with the species frequently feeding on carrion (pterosaur bones have been found in velociraptor guts, for instance) and carcasses left over by other predators.

Velociraptors died out along with the remaining species of dromaeosauridae in the run up to, and as a result of, the Cretaceous-Tertiary mass-extinction event that occurred approximately 65.5 million years ago. Despite this, elements of their anatomy and appearance can still be seen today – albeit in heavily evolved forms – in many species of bird.

DID YOU KNOW? *Modern-day hawks and eagles attack their prey in a similar way to velociraptors*



The statistics…

Velociraptor

Group: Theropod

Family: Dromaeosauridae

Length: 2m (6.6ft)

Height: 0.8m (2.5ft)

Weight: 113kg (200lb)

Location: Asia, eg Mongolia

Period: Late Cretaceous

This is an accurate representation of a velociraptor, being covered in feathers and attacking prey smaller than itself

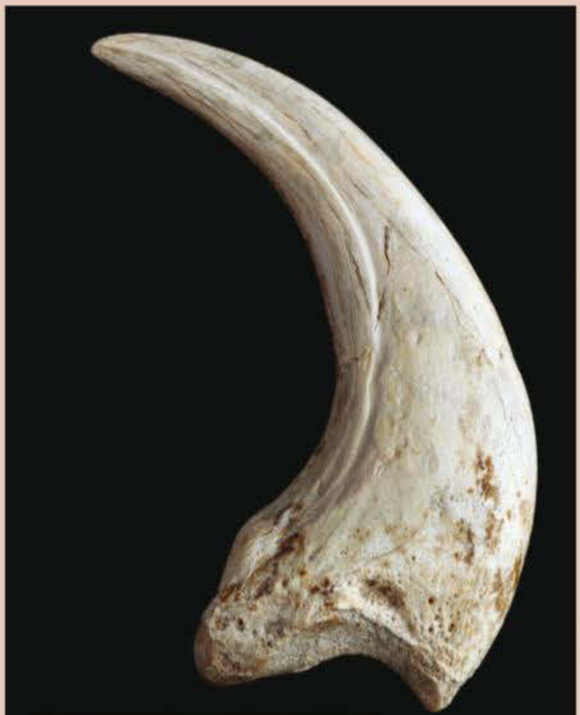
Slash or subdue?

Did velociraptors use their sickle-shaped claws to disembowel prey or for some other purpose?

The majority of non-avian theropod dinosaurs are characterised by razor-sharp serrated teeth and talon-like recurved claws, the velociraptor being no exception. Armed with a bounty of claws on both its hands and feet, the velociraptor at first glance seems to be the perfect killing machine, capable of rapidly chasing down prey before shredding their flesh with one of their knife-like tools. Well, that was at least the commonly accepted theory among palaeontologists until late in 2011, before a new study by a team of international dinosaur experts suggested an entirely different use for them.

The study suggested that far from their claws – specifically the velociraptor's much-touted 'killing claws' – being used to shred and slice prey in order to kill them prior to consumption, they were far more likely to be used in a similar way to the talons of modern-day hawks and eagles. This entails the birds using their talons as a gripping tool, snaring prey of a lesser body size, pinning them down with their own body weight and then often consuming them live with their beaks.

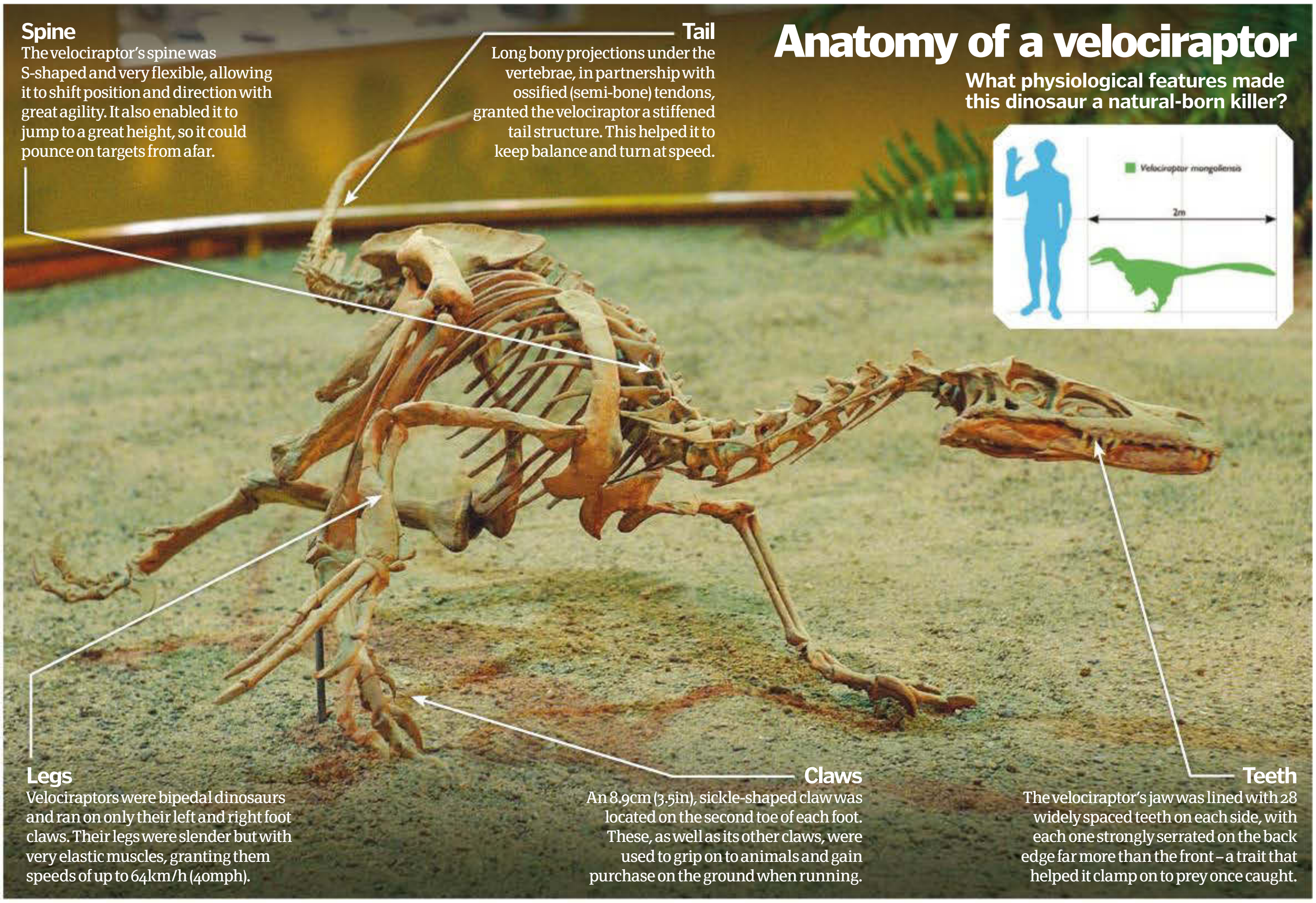
This theory is seemingly backed up by the velociraptor's feet showing morphology consistent with a grasping function, supporting a prey immobilisation model rather than the originally assumed combative one.



A fossilised claw from a velociraptor. Recent evidence has emerged that has challenged the idea that this was used as a slashing weapon

Anatomy of a velociraptor

What physiological features made this dinosaur a natural-born killer?



Spine
The velociraptor's spine was S-shaped and very flexible, allowing it to shift position and direction with great agility. It also enabled it to jump to a great height, so it could pounce on targets from afar.

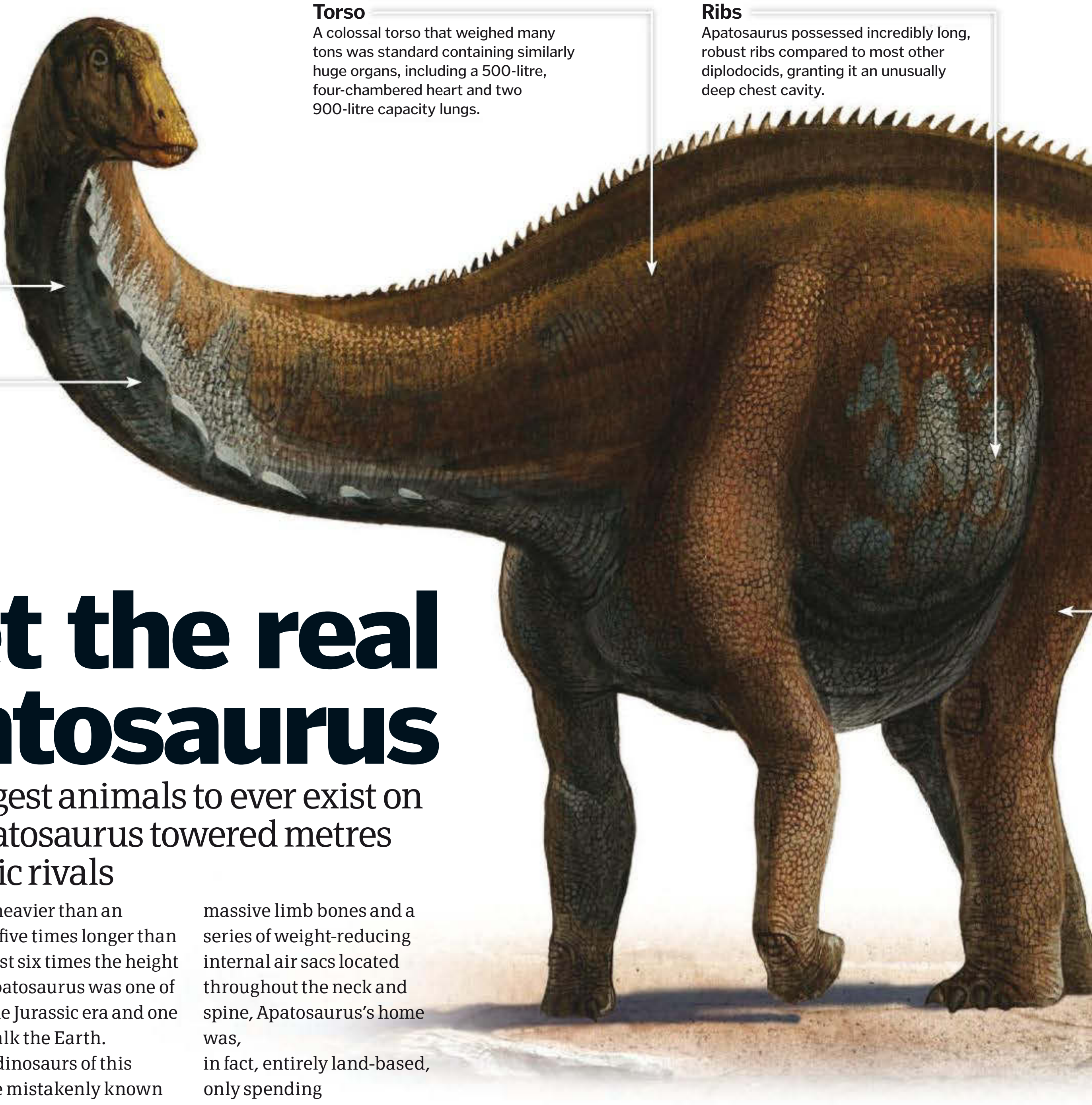
Tail
Long bony projections under the vertebrae, in partnership with ossified (semi-bone) tendons, granted the velociraptor a stiffened tail structure. This helped it to keep balance and turn at speed.

Legs
Velociraptors were bipedal dinosaurs and ran on only their left and right foot claws. Their legs were slender but with very elastic muscles, granting them speeds of up to 64km/h (40mph).

Claws
An 8.9cm (3.5in), sickle-shaped claw was located on the second toe of each foot. These, as well as its other claws, were used to grip on to animals and gain purchase on the ground when running.

Teeth
The velociraptor's jaw was lined with 28 widely spaced teeth on each side, with each one strongly serrated on the back edge far more than the front – a trait that helped it clamp on to prey once caught.

© SPL; Ben Townsend; Matt Martyniuk



Head
Apatosaurus had a deep, slender skull filled with long peg-like teeth. These broad, rounded teeth were excellent at stripping off leaves from branches.

Torso
A colossal torso that weighed many tons was standard containing similarly huge organs, including a 500-litre, four-chambered heart and two 900-litre capacity lungs.

Ribs
Apatosaurus possessed incredibly long, robust ribs compared to most other diplodocids, granting it an unusually deep chest cavity.

Neck
As with other sauropods, the Apatosaurus's neck vertebrae were deeply bifurcated, carrying paired spines. The neck was also filled with many weight-saving air sacs.

Meet the real Brontosaurus

One of the largest animals to ever exist on Earth, the Apatosaurus towered metres over its Jurassic rivals

Around four times heavier than an African elephant, five times longer than your car and almost six times the height of a full-grown human, Apatosaurus was one of the largest dinosaurs of the Jurassic era and one of most gigantic to ever walk the Earth.

As is typical with large dinosaurs of this period, Apatosaurus (once mistakenly known as Brontosaurus) was a herbivore, consuming vast quantities of foliage and grasses over the lands that now form modern-day North America. Interestingly, despite its size, its name is derived from the Greek 'apate' and 'saurus', which translate as 'deception lizard' – a name bestowed by its original discoverer, American palaeontologist Othniel Charles Marsh.

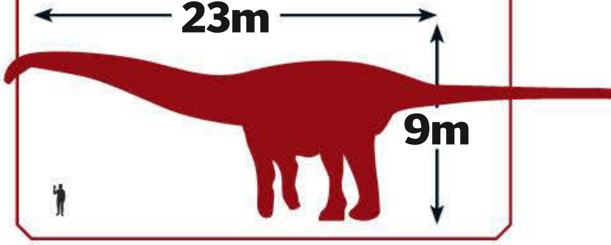
Prior to the 1970s, Apatosaurus, along with many other sauropods, were considered largely aquatic creatures that relied on being partially submerged in swamps and lakes to remain stable – a view seemingly confirmed by their colossal bulk. However, recent evidence has demonstrated that through a combination of massive limb bones and a series of weight-reducing internal air sacs located throughout the neck and spine, Apatosaurus's home was, in fact, entirely land-based, only spending time at water sources to drink.

Speaking of drinking, the Apatosaurus required gallons of water per day to remain healthy, while it also needed to process vast amounts of food, spending a large proportion of each day grazing. It did this with few predators, as only the largest carnivorous dinosaurs had any chance of bringing down an Apatosaurus, largely thanks to its size. It also had a deadly weapon in its tail, which was capable of being swung at great velocity at any foes.

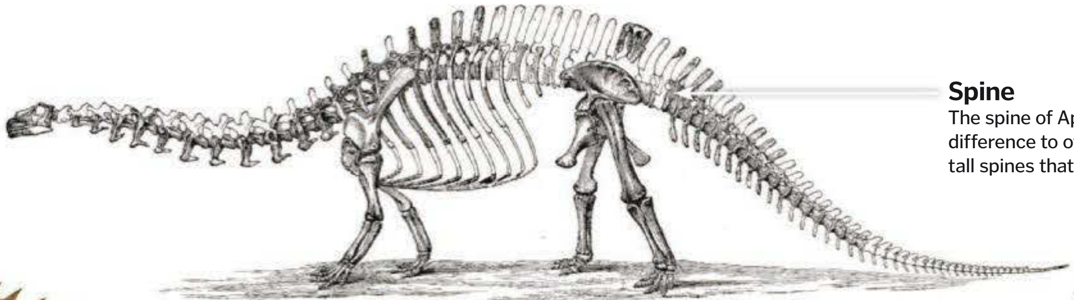
Despite its defensive prowess, however, the Apatosaurus could not battle off extinction, with it falling to a medium-sized extinction event around 150 million years ago.

Apatosaurus vs human

How would this enormous dinosaur have sized up to a person?

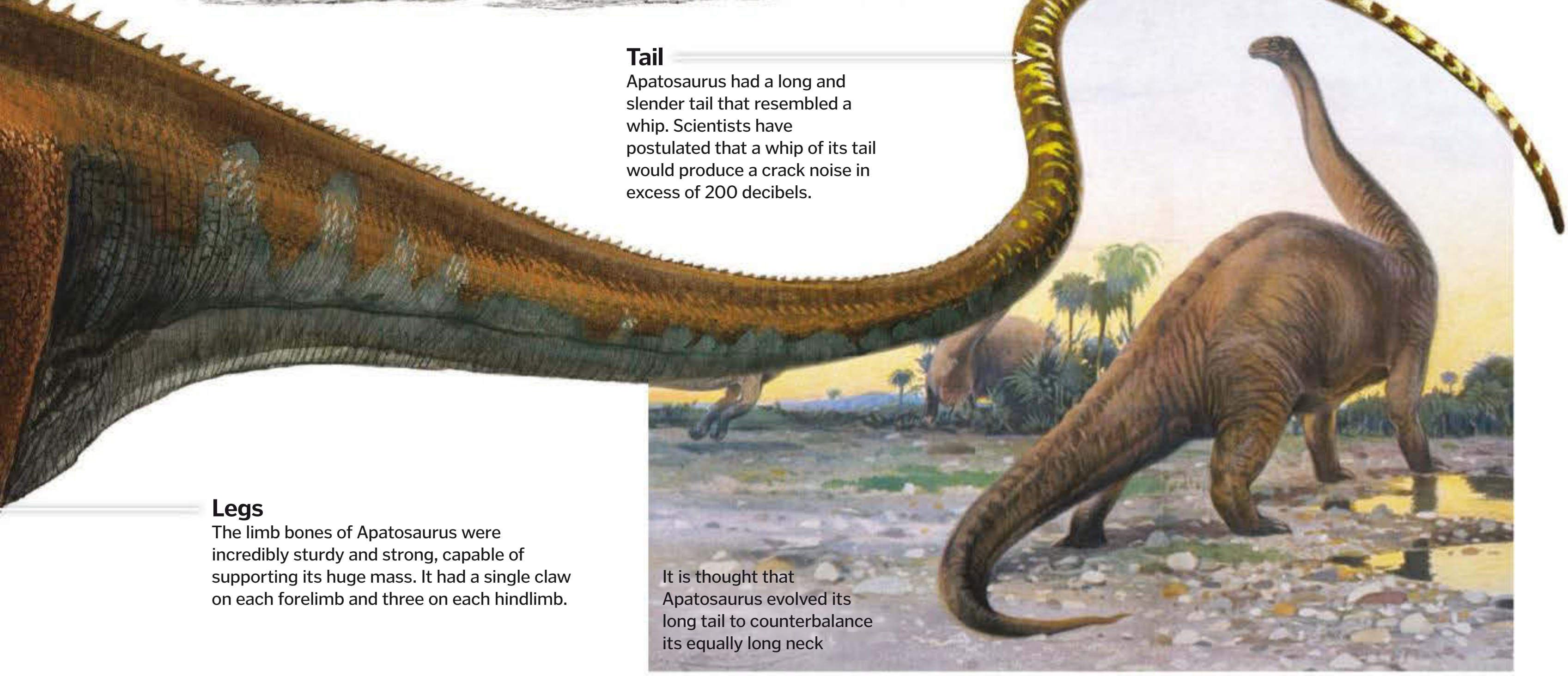


DID YOU KNOW? *Apatosaurus skeleton fragments have been found in Wyoming, Colorado, Oklahoma and Utah*



Spine

The spine of Apatosaurus was interesting in its difference to other sauropods, possessing incredibly tall spines that made up half its total height.



Tail

Apatosaurus had a long and slender tail that resembled a whip. Scientists have postulated that a whip of its tail would produce a crack noise in excess of 200 decibels.

Legs

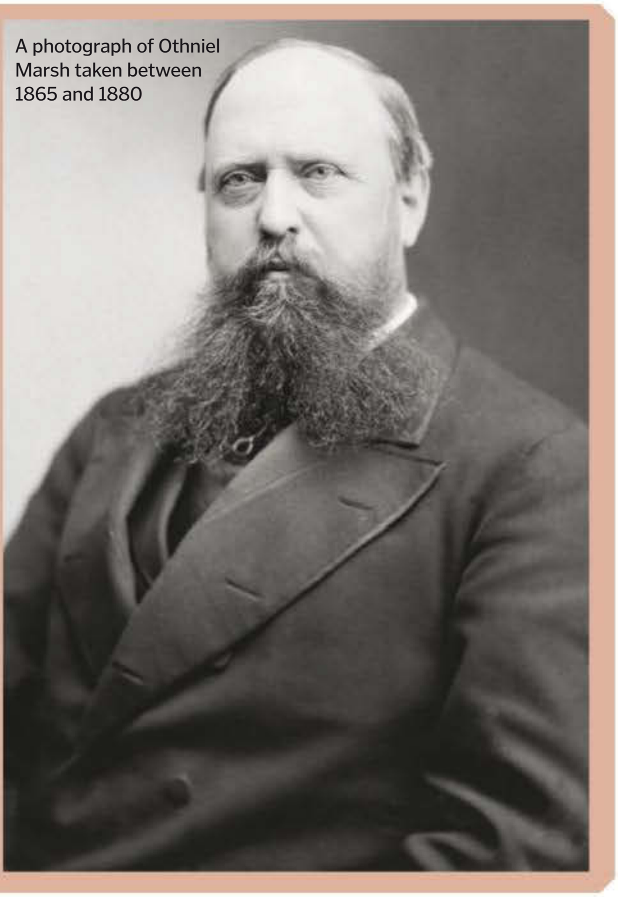
The limb bones of Apatosaurus were incredibly sturdy and strong, capable of supporting its huge mass. It had a single claw on each forelimb and three on each hindlimb.

It is thought that Apatosaurus evolved its long tail to counterbalance its equally long neck

The bone wars

During the beginning of the golden age of modern palaeontology, two prominent American palaeontologists, Edward Cope and Othniel Marsh, had a falling out over excavated dinosaur remains, with the men then proceeding to attempt to beat each other to unearth and describe new species of dinosaur. In this rush to become the foremost palaeontogist of the age, Marsh described first in 1877 and then later in 1879 two supposedly separate species of dinosaur. He named the first one Apatosaurus and called the second one Brontosaurus.

Following this, the name of Brontosaurus became world famous, with a complete skeleton mounted and displayed in the Peabody Museum, Yale, under the Marsh title in 1905. However, Marsh in his haste had made a terrible mistake. The Brontosaurus was actually just a fully-grown Apatosaurus and, since the Apatosaurus had been described first in 1877, its name took precedent, with 'Brontosaurus' made officially redundant in the early-20th century. Interestingly, however, as the Brontosaurus name had become firmly fixed in the public consciousness, it remained far more popular and is still in use to this day to the chagrin of many dinosaur experts.



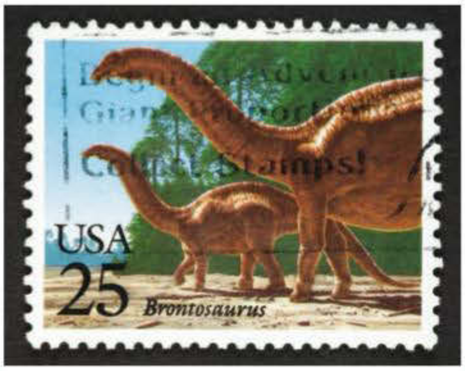
A photograph of Othniel Marsh taken between 1865 and 1880

Stamp scandal

In 1989, the US Post Office decided to release a special edition set of four stamps depicting famous dinosaurs. These included a Tyrannosaurus, Stegosaurus, Pteranodon and, interestingly, a Brontosaurus.

The latter was included despite the fact that, as noted in 'The bone wars' boxout, the name 'Brontosaurus' had been made officially redundant in the early-20th century.

The fallout from this was massive, with many palaeontologists and dinosaur enthusiasts accusing the US Post Office of promoting 'scientific illiteracy' and re-opened a bone war-style feud between others. Indeed, even the celebrated palaeontologist Stephen Jay Gould got involved, writing a famous defence of the Brontosaurus name in his *Natural History* magazine piece 'Bully for Brontosaurus'.



© Corbis; Alamy

Ankylosaurus

A club-wielding brute of a creature, this tough dino had the power to break bones

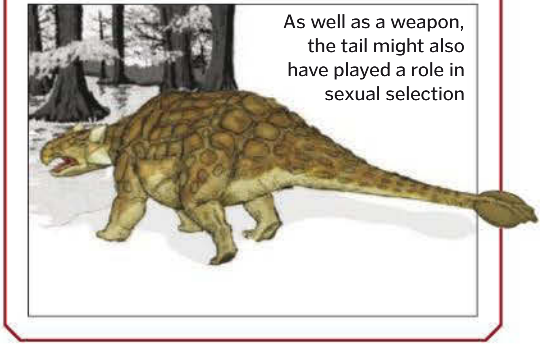
Ankylosaurus was one of the largest ankylosaurs, a genus of armoured dinosaurs that lived throughout North America between 75 and 65.5 million years ago. Famous for both its brutal tail-mounted club and its immense bone plate armour, the Ankylosaurus was a defensive titan, capable of fending off rivals many times its size.

Ankylosaurus's focus on defence was born out of its herbivorous nature, with its entire body geared towards the consumption of foliage. From its low-slung body, rows of leaf-shaped cropping teeth, short front legs, wide feet and cavernous stomach, the Ankylosaurus was the consummate browser, devouring vegetation whole with little shredding or chewing. Indeed, studies have indicated that the skull and jaw of the Ankylosaurus were structurally tougher than many similar, contemporary dinosaurs.

In fact, evidence suggests that Ankylosaurus – and ankylosaurs in general – were adept survivors. But despite their impressive armour, weaponry and sustainable diet, they could not cope with the Cretaceous-Tertiary extinction event that wiped out all terrestrial dinosaurs approximately 65.5 million years ago. Only a few fossils of this prehistoric herbivore have been excavated to date – most coming from the Hell Creek Formation in Montana, USA.

Club members only

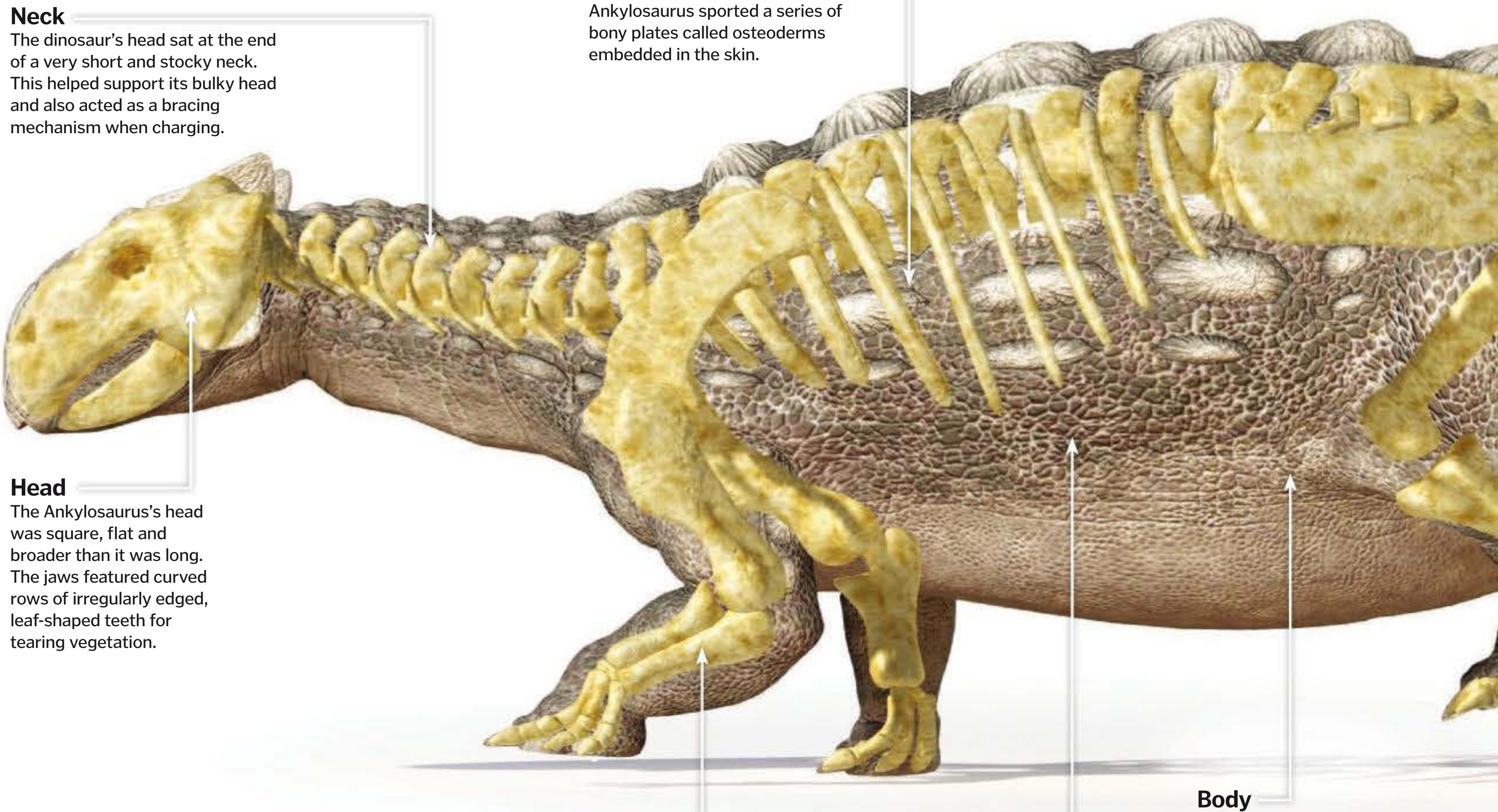
The well-known tail club of the Ankylosaurus was one of the most lethal weapons sported by any dinosaur. The club was made from several large bone plates called osteoderms that were fused into the last few vertebrae of the animal's tail. Behind these vertebrae several others lined with thick, partially ossified tendons completed the club's handle, resulting in a structure that, when swung, was capable of dealing out a lot of damage. Indeed, a study in 2009 suggested that the tail clubs of fully grown ankylosaurs could easily crush and break bone with a force capable of caving in an assailant's skull. Whether or not the animal purposely aimed the club to cause damage remains unclear at this point.



As well as a weapon, the tail might also have played a role in sexual selection

Ankylosaurus anatomy

Get to know the key biology of this tank-like dino



Neck
The dinosaur's head sat at the end of a very short and stocky neck. This helped support its bulky head and also acted as a bracing mechanism when charging.

Osteoderm
Covering much of the body Ankylosaurus sported a series of bony plates called osteoderms embedded in the skin.

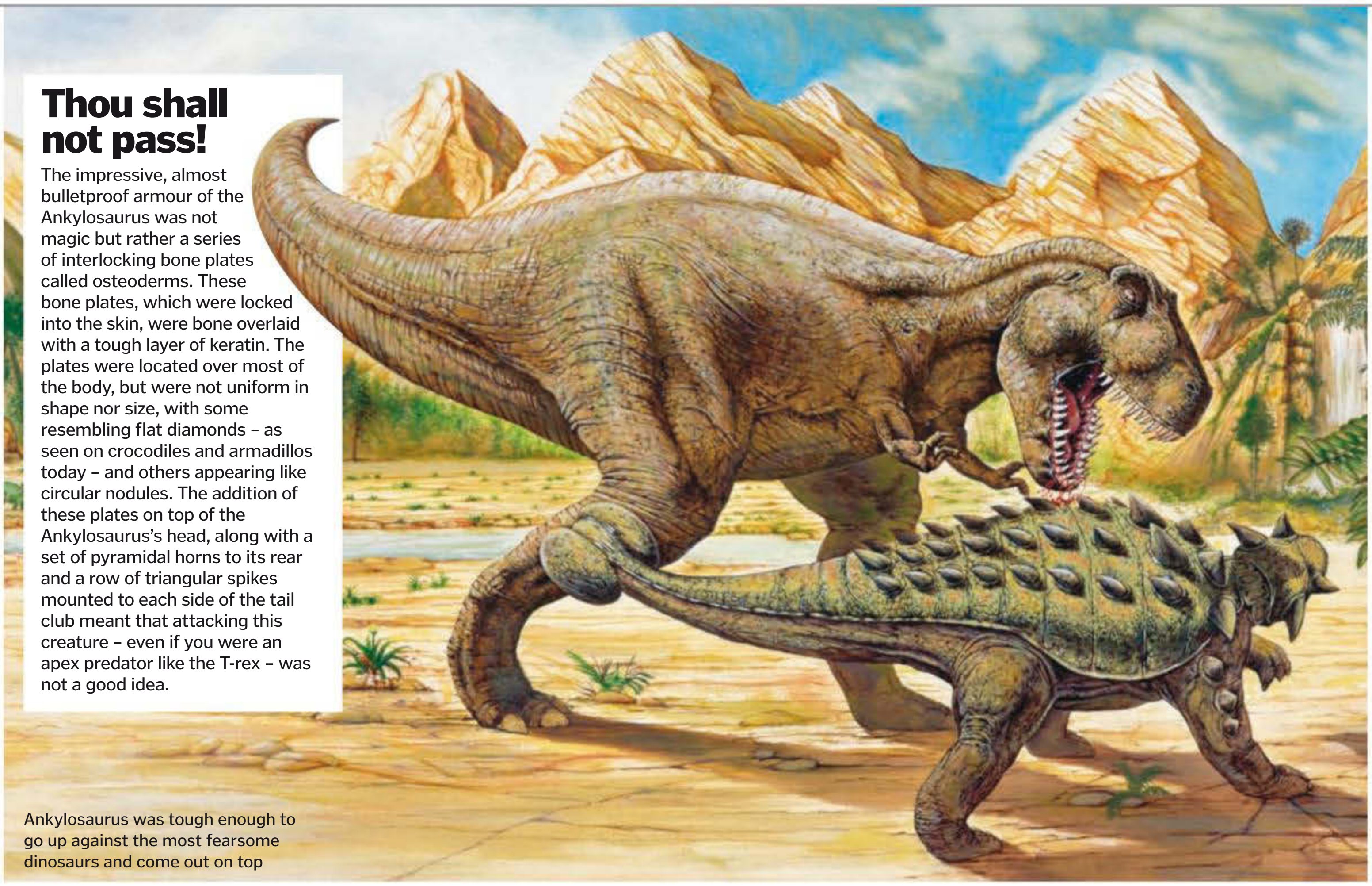
Head
The Ankylosaurus's head was square, flat and broader than it was long. The jaws featured curved rows of irregularly edged, leaf-shaped teeth for tearing vegetation.

Front leg
Powerful but short legs supported the front half of the animal. The wide foot area of these forelegs granted good traction and stability.

Stomach
The only part of the dinosaur that was unarmoured, the underbelly hung low to the ground. Predators would try to tip ankylosaurs over to access this weak point.

Body
The bulk of the near-six ton beast was contained within its low-slung body. This was covered with armoured bone plating and topped with spines.

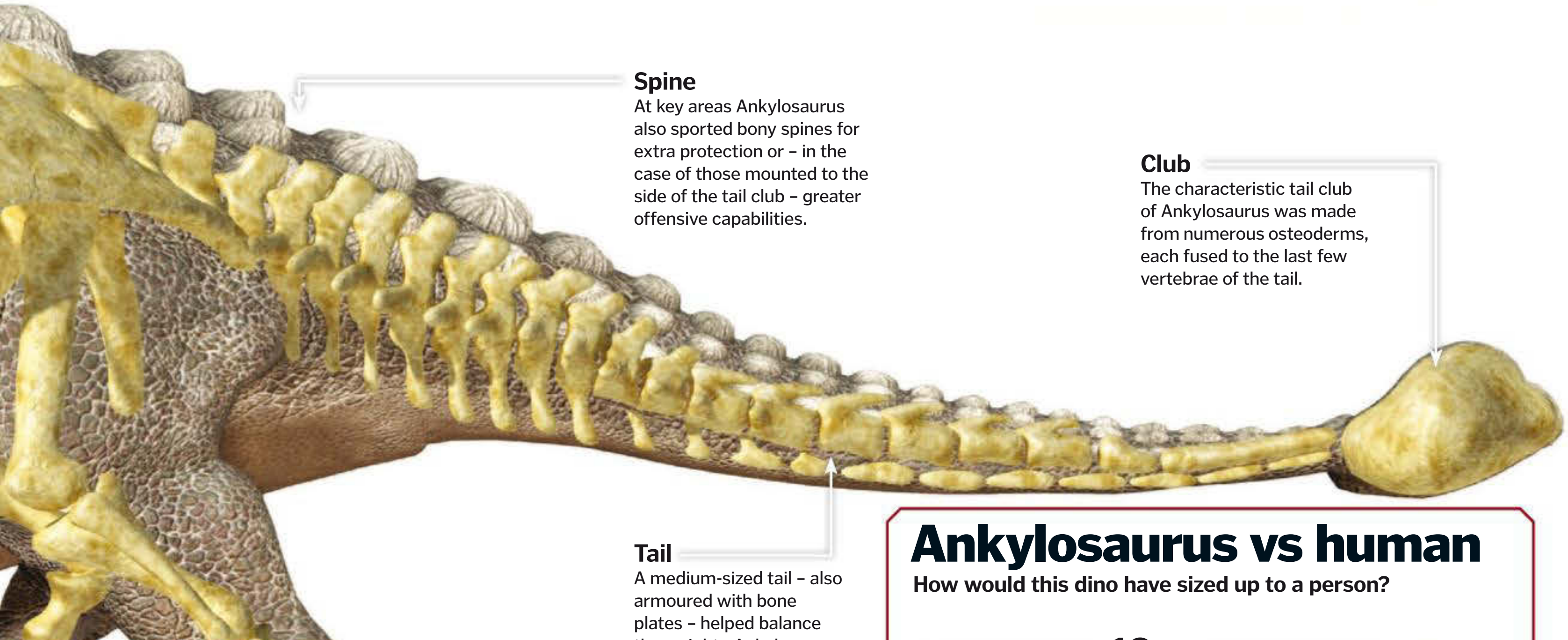
DID YOU KNOW? *The Ankylosaurus' club tail could have been used for combat or to attract a mate*



Thou shall not pass!

The impressive, almost bulletproof armour of the Ankylosaurus was not magic but rather a series of interlocking bone plates called osteoderms. These bone plates, which were locked into the skin, were bone overlaid with a tough layer of keratin. The plates were located over most of the body, but were not uniform in shape nor size, with some resembling flat diamonds – as seen on crocodiles and armadillos today – and others appearing like circular nodules. The addition of these plates on top of the Ankylosaurus's head, along with a set of pyramidal horns to its rear and a row of triangular spikes mounted to each side of the tail club meant that attacking this creature – even if you were an apex predator like the T-rex – was not a good idea.

Ankylosaurus was tough enough to go up against the most fearsome dinosaurs and come out on top



Spine
At key areas Ankylosaurus also sported bony spines for extra protection or – in the case of those mounted to the side of the tail club – greater offensive capabilities.

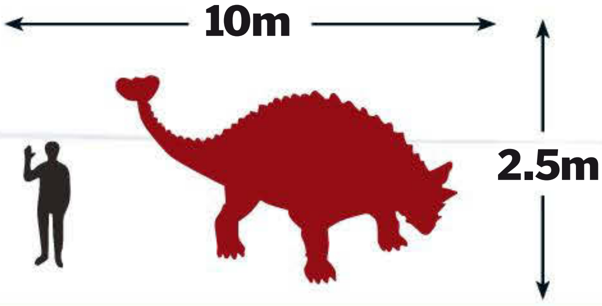
Club
The characteristic tail club of Ankylosaurus was made from numerous osteoderms, each fused to the last few vertebrae of the tail.

Tail
A medium-sized tail – also armoured with bone plates – helped balance the weighty Ankylosaurus and provided the power to cause maximum damage with its club.

Rear leg
Equally powerful – if not more so – but longer than the Ankylosaurus's forelegs, the rear legs reached up to about 1.7m (5.6ft) at the hip.

Ankylosaurus vs human

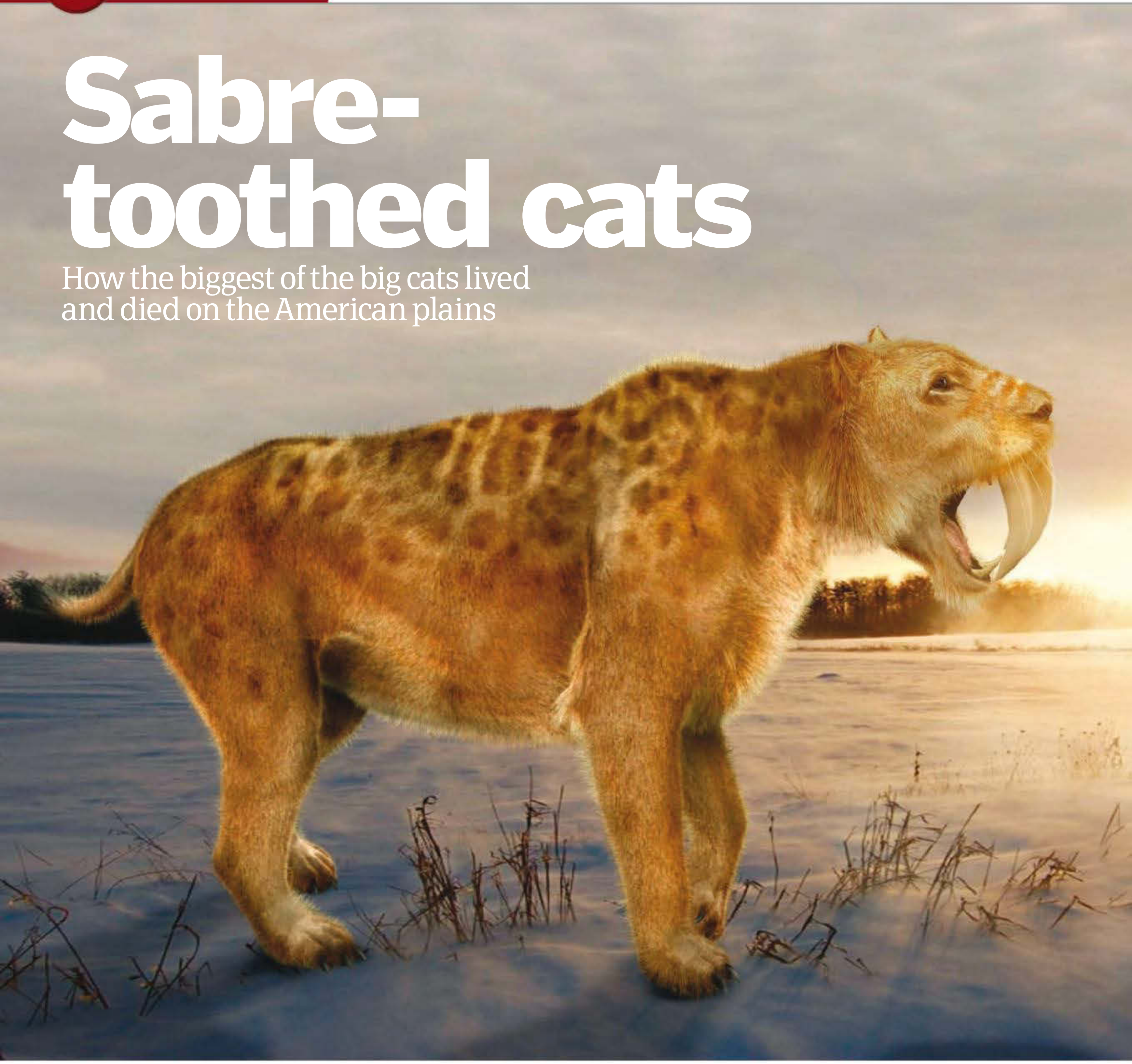
How would this dino have sized up to a person?



© Alamy; Getty

Sabre-toothed cats

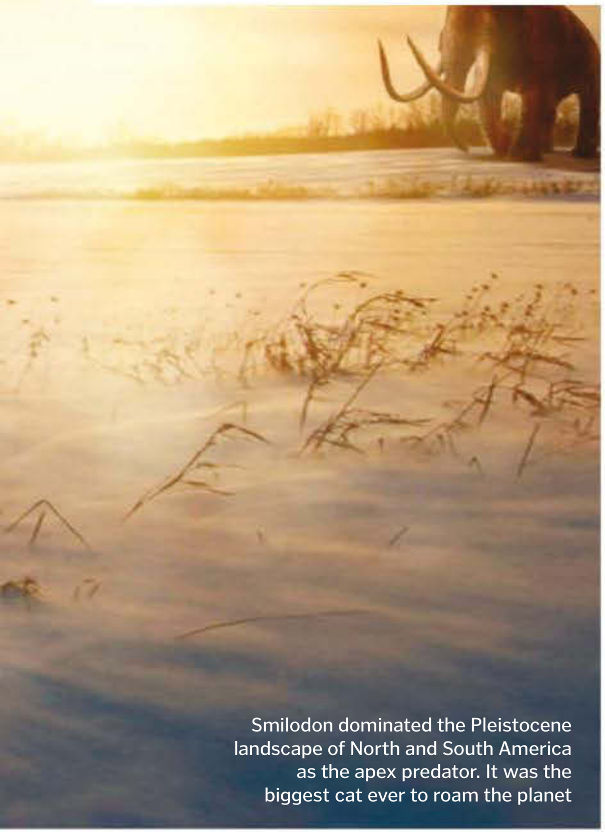
How the biggest of the big cats lived and died on the American plains



It's a common misnomer, but the sabre-toothed tiger never existed. What most people think of when someone mentions a sabre-tooth is Smilodon, a very successful cat of which there were three to five different species. Although believed to have originated in Africa and Eurasia, these felines lasted the longest in the Americas, right up to the end of the last ice age 10,000 years ago. Smilodon gracilis was a relatively small feline weighing about the same as a human. It died out around 500,000 BCE having been usurped by its descendant, the significantly larger Smilodon fatalis, an animal weighing in at 160-280 kilograms (350-620 pounds) – about the same as today's Siberian tiger. But its close relative Smilodon populator is the biggest big cat on record, a whopping 220-360 kilograms, 1.4 metres (4.6 feet) at the shoulder and up to 2.6 metres (8.5 feet) long, with its characteristic upper canines reaching an eye-watering 30 centimetres (12 inches)! And unfortunately for us (or perhaps for Smilodon populator), this sabre-toothed cat was around long enough to see Homo sapiens appear on the scene and interact with them.

Smilodon populator was a similarly social carnivore to African lions and hunted in small groups, but its muscular build and limb length meant that it ambushed prey rather than chasing it down. It preferred the large mammals of the time that were common to the Americas: juvenile mammoths and mastodons, American camels, ground sloths and

DID YOU KNOW? *The name Smilodon is derived from the Greek for chisel- or knife-tooth*



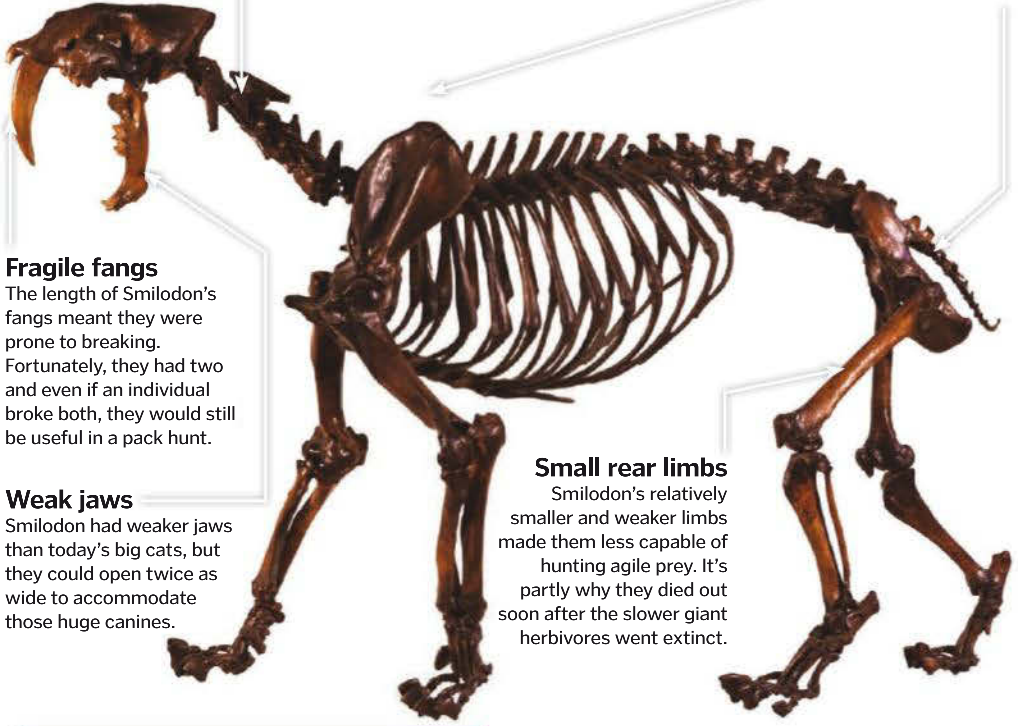
Smilodon dominated the Pleistocene landscape of North and South America as the apex predator. It was the biggest cat ever to roam the planet

macrauchenia (extinct llama-like mammal). Several Smilodon would use their combined body weight to drag prey down and subdue them, before using their sharp teeth like daggers to inflict mortal wounds to the neck.

It's likely that Smilodon populator preyed on early humans on occasion, but it's just as likely that the success of Homo sapiens, and our competition for the megafauna they hunted, ultimately sounded the major death knell for this legendary feline species.

Sabre-tooth skeleton

Explore one of these ancient feline predators from the inside out



Thick neck
The powerful neck was used to help sink its teeth deep into its victims.

Broad shoulders
Smilodon populator had especially powerful forelimbs, built more like today's hyena, perfect for wrestling with large prey.

Bob tail
Sabre-tooths had a tail, but it was stubby and more like a bobcat's than a modern lion's.

Fragile fangs
The length of Smilodon's fangs meant they were prone to breaking. Fortunately, they had two and even if an individual broke both, they would still be useful in a pack hunt.

Weak jaws
Smilodon had weaker jaws than today's big cats, but they could open twice as wide to accommodate those huge canines.

Small rear limbs
Smilodon's relatively smaller and weaker limbs made them less capable of hunting agile prey. It's partly why they died out soon after the slower giant herbivores went extinct.

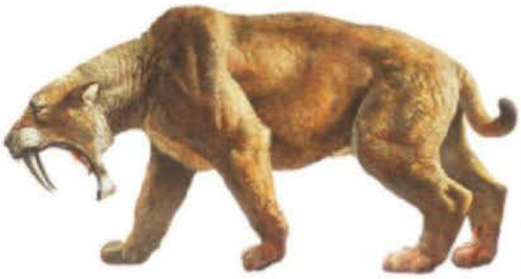
Palaeontologists have assembled hundreds of prehistoric animals from the bones found at La Brea

Big cat boneyard

The Page Museum, Los Angeles, is located on a site of great palaeontological significance. It's home to La Brea Tar Pits, an ancient death-trap for megafauna that roamed the area 10,000-40,000 years ago. Here, subterranean bitumen leaked to the surface creating a gloopy bog of tar. Mammals like the mastodon (an elephant ancestor) and other giant herbivores stumbled into the morass and drowned. Predators such as Smilodon were attracted by the alarm calls of struggling prey and converged on what seemed to be an easy meal, only to become trapped themselves. The asphalt from the tar pit was being used by settlers 300 years ago, but it wasn't until 1875 that William Denton discovered La Brea's scientific importance. Since excavations started in 1913, over 3.5 million fossils have been found here, including 2,500 sabre-toothed cats.

Why did cats evolve sabre teeth?

Sabre teeth are a great example of convergent evolution: many species evolved this same trait independently around this time. So what was the benefit of these deadly weapons? The apex predators of this era were equipped with disproportionately huge fangs because, as simple as it sounds, the animals they hunted were much bigger. Modern big cats like the African lion throttle their prey by crushing the windpipe – a fine tactic to finish a dainty gazelle, but if you're attacking beasts significantly beyond your weight category – like the woolly mammoth – hanging onto their throat until they suffocated wasn't an option. Smilodon used their dagger-like canines like an assassin, surprising its intended meal by stabbing at the throat or ripping its soft belly, then retreating and allowing the victim to weaken before moving in for the kill.



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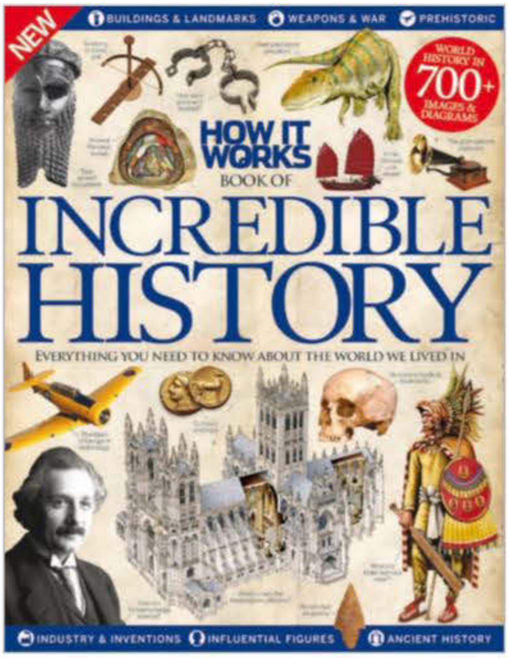
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